DESIGN AND IMPLEMENTATION OF AN APPROPRIATE MOTOR CONTROLLER TO IMPROVE THE RANGE OF AN E-BIKE

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A Final Year Design Project (FYDP) submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of B.Sc in EEE

Department of Electrical and Electronic Engineering
Brac University
April, 2023

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Declaration

It is hereby declared that-

1. The Final Year Design Project delivered is my/our own unique work while pursuing a degree at Brac University.
2. Except where properly referenced through complete and correct referencing, The Final Year Design Project does not contain any previously published or written by a third-party source.
3. The material in the final year design project has not been approved or submitted for any other degree or certificate at a university or other institution.
4. We have given credit to all major sources of assistance.

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Approval

The Final Year Design Project (FYDP) titled "Design And Implementation of an Appropriate Motor Controller to Improve The Range of an E-Bike" submitted by

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of Spring, 2023 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of B.Sc in EEE on 27th April, 2023.

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Ethics Statement

We thus state and certify that this project, Design, And Implementation Of An Appropriate Motor Controller To Improve The Range Of An E-Bike, complies with the criteria for the final year design project (FYDP). It was written with the help of everyone in our group working together. The analysis's auxiliary resources, including the literature review and the data gathering, have all been correctly cited. With the help of our mentors and the university, we put the project's contents into practice.

The plagiarism index of our report is found to be 7% after asking for a similarity check from the Ayesha Abed Library, Brac University.

Abstract/ Executive Summary

According to statistics, riders want to use their electric bicycles for longer trips but are constrained by their batteries' short lifespan. Nowadays electric bicycles can be modified with many different electrical mechanisms that can enhance the travel distance covered by the bike. Most often a rider wants to use a system that can give more range coverage than the regular electric bike with the bike having a simple system rather than some extra attachments on the bike to enhance the ease of riding. In order to lengthen the trip distance and battery life of an electric bicycle, this paper explores an effective approach to apply and regulate a regenerative braking system for an electric bike. The groundwork for creating a better-performing electric bike with a regenerative braking system that could be fitted to any widely accessible electric bicycle conversion kit is being assembled and experimented with in this study.

Keywords – Regenerative braking, BLDC motor, Motor controller, Back EMF.

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1.1 Introduction

In Bangladesh, the transportation sector, mainly the abundance of private and public motorized vehicles with combustion engines, is responsible for poor environmental conditions. Besides this, as the population is growing rapidly, the already existing traffic jam is getting worse every day and every regular journey in the city is taking more time than ever before.

Many approaches have been introduced in both national and international regions. As a result, research on motorized vehicles is increasing day by day. In the last decades, electric bicycles have emerged as a new kind of transportation system. Bicycles are already the common type of vehicle in some rural areas but electric bikes are more popular for use everywhere since it requires less physical effort and it does not need any petrol or diesel.

- **Conventional braking system**

Mechanical braking system: A bicycle brake reduces the speed of a bicycle by using three main types, that are rim brakes, disc brakes and drum brakes. Also, these three braking systems consist of three main components as well. Such as a mechanism for the rider to apply the pedal, a mechanism for transmitting the signals like Bowden cable and hydraulic hoses or the bicycle chain and the braking system itself [1].

Electrical Braking system: The Electrical Braking System is one of the types of the braking system, which is based on the brake pedal depression strategy and is similar to the Drum Braking System but the only difference is that the Electrical Braking System is related to the Electromagnetic Force while Drum Brakes use Hydraulic Pressure to apply the brakes. whenever a user pushes the brake pedal if the braking process happens with electric power which is called an electrical braking system. In this system, the electric current controls the brake through an electromagnet [1].

- **Regeneration Mechanism:** Regenerative braking system is a type of kinetic energy recovery system that transfers the kinetic energy of an object in motion into stored energy to slow a particular vehicle. During braking, the kinetic energy is converted into heat energy due to friction. The regenerative braking system tries to recover this kinetic energy before it is converted into heat energy[2][3]. The current going to the motor while braking can be stored and used later by diverting. Generally, the regenerative braking system is applied in two-wheelers and four-wheelers vehicles. However, it can be implemented into two-wheelers as well. In designing a regenerative braking system generally, the supercapacitor is used most of the time in shunt with the battery bank which exceeds the lifetime of the battery [4]. Also, one of the most common practices is to use a boost converter. In the boost converter-based scheme by increasing back emf, the battery is charged. As the back emf of the motor is lesser than the battery voltage, it needs to use a boost converter to magnitude [5].

- **Dynamo:** Bicycle dynamos are alternators equipped with permanent magnets that can produce AC current. Dynamo can be used to convert mechanical energy to electrical energy. Alternating current can normally be produced using the dynamo. This current can power devices, which work on AC directly and can be converted and used for devices working on DC. The amount of power generated from a dynamo by pedaling is sufficient to power the devices, which require low power [6].
- **Cadence System:** Pedal assist is a concept that can only be achieved when the motor is simulated by the user. In order to detect the motor or if the user is pedaling or not we add a cadence sensor. A cadence sensor is a relatively small set of three devices that can easily mount to the bike using a spoke magnet and hall magnet[7].

1.1.1 Problem Statement

During the past few years, a great advance has been produced in the automotive industry, a strategic sector with a high impact. Many approaches have been introduced in automation of cars and other vehicles using electrical devices in both international and national regions. In Bangladesh In the transportation sector mainly the abundance of private and public motorized vehicles with combustion engines are responsible for poor environmental conditions. Besides this as the population is growing rapidly, the already existing traffic jam is getting worse every day and every regular journey in the city is taking more time than ever before. Even though there are many options when traveling from one place to another like bus, uber, CNG and other transportation when it comes to time efficiency or cost-effectiveness, not all options are suitable for people, as we are a developing country with a rising middle-class majority. Especially for the students, they are being affected the most for this situation as they need to go for classes every day. Most of the students usually use buses as their primary transport. Buses take way too much time to go from one place to another as they try to pick up passengers from every stoppage they can and overload the bus which wastes a lot of time for any student. So it is tough for them to get through all these hassles. The most convenient and efficient way to travel every day is by bus but using the bus as the main transportation system is extremely time-consuming. To solve this problem we are making an electric bicycle which is considered to be an environment-friendly and fuel-conserving, affordable mode of transport with the increasing user group and rapid innovation in the production system. Electric Bicycles can be a solution to traffic jams along with Carbon dioxide(CO_2) emissions in densely populated areas like Bangladesh and nowadays, it is becoming more popular than other private transports in the country. According to the new policy for automobiles targeted to integrate energy-efficiency vehicles into the ecosystem, the government is eyeing to increase the share of EVs to at least 15% of all registered vehicles by 2030. As almost 100% of the electric bikes are imported from other countries, the price of the bicycle increases with the taxes that need to be paid when importing, ultimately the cost of the bicycle increases as well. We should focus more on manufacturing the parts in our country which can drastically reduce the cost of the electric bicycle [8].

1.1.2 Background Study

In Bangladesh, the transportation sector, mainly the abundance of private and public motorized vehicles with combustion engines, is responsible for poor environmental conditions. Besides this, as the population is growing rapidly, the already existing traffic jam is getting worse every day and every regular journey in the city is taking more time than ever before[9]. Especially for students, it is becoming harder for them to go to schools, colleges, and universities because of the traffic congestion. To pursue sustainable and accessible mobility[10] on campuses or offices Electric Bicycles can be a solution to traffic jams along with Carbon dioxide(CO_2) emissions in densely populated areas like Bangladesh and nowadays, it is becoming more popular than other private transport in the country. According to the new policy for automobiles targeted to integrate energy-efficiency vehicles into the ecosystem, the government is eyeing to increase the share of EVs to at least 15% of all registered vehicles by 2030[11]. Because practically all electric bikes are imported from other countries, the price of the bicycle rises due to the taxes that must be paid while importing, and therefore the price of the bicycle rises as well [12].

Several research works have been carried out by different researchers about electric bikes. In one paper the authors explore the barriers to bicycle adoption, in particular for a tropical environment, and hence propose a technical solution to overcome the barriers by doing test runs[13]. Basically, e-bikes can help us to circumvent using green energy that is good for the environment and public health. In another article, the authors discussed the impact of the e-bicycle as a solution to congestion and other commuting issues. This study investigates the median mode substitution reported in the article is highest for public transit(33%), conventional bicycle(27%), automobile(24%), and walking(10%) [14]. Additionally, in one paper the authors experimented with the operation of an electric bicycle based on mathematics and the effect of the parameters on how the power generation is needed and developed the model based on optimized mechanical[15]. Furthermore, some other research has been conducted to fabricate an optimal design for converting a regular bicycle to an e-bike. In a paper, the authors have discussed the comparison between two types of bicycles Then, e-bike travel behavior and modal substitution research were also discussed the performance and operation (complementary) domains to understand the characteristics of e-bike riders. Finally, based on the core and complementary domains, they proposed a conceptual ELOS framework to convert a regular bicycle to an e-bike[16]. Moreover, In another article that we have gone through, the authors have implemented an e-bike by using an effective regenerative braking system so that the energy we lost using a bicycle can be recovered. In this paper, they implemented an e-bicycle that can convert mechanical energy to electrical energy in braking action[17]. Furthermore, in an article the authors are able to design an optimized electric bicycle for youths with neurodevelopmental disabilities, this adapted e-bike is provided with some ultrasonic sensors that help to maintain posture and balance. This is a very sophisticated article that was obtained by demonstrating that an e-bike can be improved to provide better space orientation in the future[18]. Also, we have added some other papers about the constraints we can face to implement the project. In one paper, some authors analyzed the energy crisis and the lack of charging stations in

Bangladesh[19][20]. In another paper, the author explains how e-bikes can be sustainable in the long run when it comes to commuting to different places[21]. E-bicycle projects can be very impactful to all people because of the energy crisis that we are going through. By using e-bikes as our primary commuter system, we can save a lot of money and also not have to waste money on petrol or diesel[22][23]. Also in some papers, authors discuss how it can be effective for our health, not only that riding an electric bicycle has a positive impact on the environment in more than one way [24][25][26][28][29]. Not only does it impact the environment or societal or health it also can play a big role in the Bangladeshi industries since it does not need any registrations[30][31]. Even though some articles or websites have mentioned some of the risk management procedures, we have planned on designing a model that has an alternative plan for providing safety for riders [32][33].

Since these above-mentioned articles are very sophisticated and well-built, for solving these kinds of problems one must need to have knowledge about discrete parts also, there are various scopes for improvement so we must take the steps. These solutions involve an in-depth analysis of today's bicycle marker to its mechanism. Besides this, we need to know how to benchmark and how to do the project architecture. After that a project needs to be designed with different software then the system needs to be tested and finally completed into a prototype. For all those reasons designing and implementing an e-bike is a complicated task. The system proposed in this proposal combines the attributes and mechanisms from different sectors together to make adjustments to the electrical bicycle. We have gathered knowledge by going through papers and also we have talked to some stakeholders who help us to understand their demand and also some stakeholders to help us to understand the bicycle market.

Currently, the world is facing global warming due to burning fossil fuels and undesirable economic implications caused by fluctuating commercial fuel prices. Simon Nicholas, a researcher at the U.S.-based Institute for Energy Economics and Financial Analysis (IEEFA) said that Bangladesh’s power sector has increasingly relied on imports of fossil fuels, including Liquefied Natural Gas (LNG) which is a “very volatile commodity” that risks becoming too expensive for poorer importing countries[25].

1.1.3 Literature Gap

The background research that we have done for this project shows the substantial need for advancement in such a sector, not only in one particular subsystem but in entire systems consisting of different customizable features. The accuracy of the control system of the e-bike is very crucial. Researchers have used both commercially available devices and manually designed ones but many of the papers have some important aspects missing such as optimization techniques of the regenerative braking system, some other papers may lack the procedure of how to increase the recoverable energy and battery efficiency/power[34]. There are almost no papers found on making regenerative braking systems less bulky, as reducing the weight of the whole system can give an efficient system. To make the system more feasible this is an important aspect to work on which is the most significant literary gap in the topic. Also, it is more convenient to introduce driving patterns to the regenerative braking system so that energy consumption shall be minimum and more energy can be restored to use later, some of the papers lack enough research on this topic as well. Further research should be done on the development of the anti-lock braking system (ABS), which is based on the current braking design scheme[36].

1.1.4 Relevance To Current And Future Industry

Laboratory experiments that have been used to demonstrate the regenerative braking system. Furthermore, the necessary data is gathered under constant load conditions, but the actual situation will vary because the load varies in various circumstances.

However, in the future, based on the proposed research work, analyzes of the engines of various high-rated vehicles can be carried out. Currently, we are using the commonly used Sensorless BLDC motor control which is sometimes called sensorless trapezoidal control of BLDC motors which uses back EMF (BEMF) for determining the location of the motor's rotor. We can use further improved motor controllers like using 'Fuzzy logic controllers with less loss and better speed-controlling accuracy to improve overall performance[2]. The inclusion of a 'Torque sensor-based pedal assist system' can further improve the performance of the e-bike as well[34]. Also, it can be marketed in order to make braking energy available on a larger scale. Exploring this work from a commercial perspective, therefore, becomes a lucrative area of research. Additionally, in the future different types of motors can be used to improve the design which can be more effective as a back emf generator. Regenerative braking will be included into new drive train designs, thus energy loss will be reduced in electric systems. Furthermore, the inclusion of a better-performing battery like lithium-phosphate can improve the performance of the bike in future iterations of the design as well[7].

1.2 Objectives, Requirements, Specification And Constant

1.2.1 Objectives

The modern world requires a high-technology solution to the existing and future issues of fossil fuel shortage. Given the utilization of fossil fuels, it can be projected that the life of fossil fuels will only continue for a few decades. As a result, sustainable electric bikes are the ideal alternative transportation solution. Future e-bikes are the most technologically creative answer for the next generation since they include qualities such as high mobility efficiency and pleasant riding. As a result, the following goals are mentioned in order to approach the solution:

i. Designing an optimized electric bicycle.

ii. Fabricating a suitable mechanical design.

iii. Implementation of a simpler and cost-effective system that is an efficient solution to traffic congestion.

1.2.2 Functional and Nonfunctional Requirements

Type	Requirement	Statement
Functional	Suitable mileage	Considering about 40 to 55 km of mileage depending on the situation.
	External braking control system	External regenerative braking controller allows recapturing of the back emf and feeds the voltage to the battery which extends the mileage of the e-bike.
	Chain integrated system	For better pedal assistance, the cadence sensor helps to increase the speed for a certain level.

Non - Functional	Comfort	Considering the sitting position and the form factor of the handle.
	Low Maintenance Cost	Battery may require replacement within 4-6 years, tires need low maintenance, and the body frame doesn't need any maintenance.
	Appearance	May differ through modification.
	Environment Friendly	It will not directly contribute to environmental pollution for zero CO_2 emission. This means it will not create any toxic gas and smog that result in respiratory and other health problems.[5]
	Affordability	Cost per km will be around 0.53-0.70 (BDT), which is less than any other public transportation currently available.

Table 1: Requirements(Functional And Non-Functional)

1.2.2 Specifications

Design Approach 1:

- **System Level**

SL No	System level	Specifications
1	Regenerative Braking System	A 48V, 1000W hub motor that can act as a generator while producing reverse torque and feeding it to the battery. The back EMF is the main source of the recharging battery by regenerative braking which works through an external braking control system while the voltage is dropping. Maximum power stores from dropping peak voltage to zero voltage.

2	Solar System	It would have four 12V solar panels (20W-40W each) with a total power of 80W to 160W and a total 48V voltage system, which will be used to charge our backup battery for swapping with the primary battery after its full discharge.
3	Conventional Motor Controlled System	The e-bike will have a forward motion with the help of a 48V, 20Ah battery and a 1000W motor, which will be controlled using a throttle by regulating the voltage through a speed controller.
4	Chassis Structure	A strong and sustainable chassis with Aluminum Alloy that can carry up to 200 Kg of weight. The parameters of this e-bike will be around (73-78 cm) Inseam, (68cm) length, (170mm) Crank size, (56cm) Center to top length, (24 inch E6) Rim, (40mm) Tire, (1947.79mm) Circumference of the wheel, (62.2cm) Wheel diameter.

Table 2: System Level Specification Of Approach 1

- **Component Level**

Sl No	**Component**	**Model**	**Component Descriptions**	**Specifications**	**Component Level Specification**
1	Lithium-Ion Battery	WKQX 48V, 20AH	Li-ion battery is used because of its better weight-to-power ratio. Compared to lead-acid, batteries can energize heavy motors within a short space.	48V 20Ah can approximately give (40-55)Km of travel range.	

2	BLDC/PMDC Hub Motor	(Model-GP-D30F/R/C)	Essentially linear torque(neglecting iron losses), with torque proportional to current and speed proportional to voltage. Placed in the wheel which gives better balance during its movement or dynamic situation.	48V, 1000W Can give 20Ah rated current, speed of 328 RPM and 6N rated torque. 1. Rated Voltage: 48V 2. No-load Current: 1A 3. Rated Current: 20A 4. Rated Power: 1000W 5. Speed: 328 rpm 6.Compatible Wheel Size: 20-28 inches	
3	Hub Motor Controller	SKU283119059_BD-1273592917	Can drive sine wave motors, and rectangular motors, is also suitable for Hall motors, and can support 36V, 48V, 52V. The drive motor has thicker copper bars, higher inductance accuracy, and smoother starting, and more comfortable riding.	For 48V; Rated power: 1000W; Can give a speed of 50 km/h approximately	1. Diode-1N4148 2. Capacitor - 10nF 3. Mosfet - (3N163) 4. Switch key 5. Resistors-1Kohm, 100 ohms 6. Arduino mini / Atmega328 7. Hall sensor-MH177 8. Op-amp - Op77
4	Throttle	Tbest - Tbestw3xsp2ugqv	Regulates the voltage which works to speed up or down the two-wheeler.	To control the speed of the motor.	

5	Regenerative Braking System Controller	GW-C9	Controls the back EMF procedure and it gets started when the regenerative braking switch has been pushed. It converts kinetic energy into electrical energy to prolong the running distance of the bike.	When the motor works as a generator, it uses the same ratings as the forward motor control operation. 24V/36V/48V.	1. Rectifier - (Diode and Resistor) 2. DC-DC Boost Converter (Mosfet, Diode, Inductor - 47uH, Capacitor - (0.22uF, 1uF 22pF) 3. Inverter - (Mosfet, Diode) 4. nHall Sensor - MH177
6	Solar Panel	Rich Solar	80W to 160W of solar power to charge the backup battery for extra range.	48 Volts 200 to 300 Watt panels. (Four panels with 12V, 20W-40W each)	
7	Solar Charge Controller	MPT-7210A	Converts unstable DC source to stable DC source to charge the battery using solar input. It works as a boost converter as well when needed.	Input Voltage: 12-60V Output Current: 0-10A Output Voltage: 15-90V (48V 20Ah battery to be charged using an array of 3 solar panels in series, each having 12V 20W-40W)	1. Diode - 1N4007 2. Resistor - 10k ohm, 4.7k ohm, 330 ohm, 1k ohm 3. Mosfet IRF9630, IRF540 4. Transistor (BC547) 5. Capacitor - 100uF

Table 3: Component Level Specification Of Approach 1

Design Approach 2:

- **System Level**

SL No	System level	Specifications
1	Dynamo System	A DC 6V dynamo that will produce power while the wheel is rotating. This power will be fed to the battery and this dynamo can tolerate a maximum of (13,000-19,000)rpm.
2	Solar System	It would have four 12V solar panels (20W-40W each) with a total power of 80W to 160W and a total 48V voltage system, which will be used to charge our backup battery for swapping with the primary battery after its full discharge.
3	Conventional Motor Controlled System	The e-bike will have a forward motion with the help of a 48V, 20Ah battery and a 1000W motor, which will be controlled using a throttle by regulating the voltage through a speed controller.
4	Chassis Structure	A strong and sustainable chassis with Aluminum Alloy that can carry up to 150 Kg of weight. The parameters of this e-bike will be around Inseam (73-78 cm) length, (170mm) Crank size, (56cm) Center to top length, (110cm) Body length, (24 inch E6) Rim, (40mm) Tire,(1947.79mm) Circumference of the wheel,(62.2cm) Wheel diameter.

Table 4: System Level Specification Of Approach 2

- **Component Level:**

Sl No	Component	Model	Component Description	Specifications	Components Level Specification
1	Lithium - Ion Battery	WKQX 48V, 20AH	Li-ion battery is used because of its better weight to power ratio. Compared to lead acid batteries can energize heavy motors within a short space.	48V 20Ah can give (40-55)Km of mileage.	
2	BLDC Hub Motor	(Model- GP-D 30F/R /C)	Essentially linear torque(neglecting iron losses), with torque proportional to current and speed proportional to voltage. Placed in the wheel which gives better balance during its movement or dynamic situation.	Rating: 48V, 1000W It operates on a 20Ah rated current, speed of 328 RPM and 6 Nm rated torque. 1. Rated Voltage: 48V 2. No-load Current: 1A 3. Rated Current: 20A 4. Rated Power: 1000W 5. Speed: 328 rpm Compatible Wheel Size: 20-28 inches	
3	Hub motor controller	SKU283119059_BD-12735929 17	Can drive sine wave motors, rectangular motors, and also suitable for Hall motors, can support 36V, 48V, 52V. The drive motor has thicker copper bars, higher inductance accuracy, smoother starting, and more comfortable riding.	For 48V; Rated power: 1000W; Can give the speed of 50 km/h	1. Diode - 1N4148 2. Capacitor - 10nF 3. Mosfet - (3N163) 4. Switches 5. Resistors - 1Kohm, 100 ohms 6. Arduino mini / Atmega328

4	Throttle	Tbest - Tbest w3xsp 2ugqv	Regulates the voltage which works to speed up or down the two-wheeler.	To control the speed of the motor.	
5	DC Dynamo	D775	DC dynamo converts mechanical energy into electrical energy. Mainly it works when the wheel starts rotating and it gathers that rotational energy and converts it to electrical energy.	DC 6V 13000-19000 RPM High Torque & High Power Motor	
6	Converter DC-DC		DC-DC converter is a boost or buck converter. The main working procedure is to boost or to downgrade the voltage and make it stable.	36V-48V DC-DC Converter 12V step up to 48V 20A 1000W	1. Mosfet - IRL44ZN 2. Diode 1N4007, 1N4148 3. Inductor - 100uH 4. Capacitor - 470pF, 0.1uF, 1000uF 5. Resistor - 1K, 4.7K 6. IC555
7	Solar Panel	Rich Solar	80W to 160W of solar power to charge the backup battery for extra range.	48 Volts 200 to 300 Watt panels. (Four panels with 12V, 20W-40W each)	

8	Solar charge controller	MPT-7210 A	Converts unstable DC source to stable DC source to charge the battery using solar input. It works as a boost converter as well when needed.	Input Voltage: 12-60V Output Current: 0-10A Output Voltage: 15-90V (48V 20Ah battery to be charged using an array of 3 solar panels in series, each having 12V 65W to 100W)	1. Diode 1N4007 2. Resistor 10k ohm, 4.7k ohm, 330 ohm, 1k ohm 3. Mosfet IRF9630, IRF540 4. Transistor (BC547) 5. Capacitor - 100uF

Table 5: Component Level Specification Of Approach 2

Design Approach 3:

- **System Level**

SL No	System level	Specifications
1	Cadence System	A Cadence sensor along with a black disk helps the motor to kick off. With a little amount of physical strength, it helps to rotate the wheel at a certain speed.
2	Solar System	It would have four 12V solar panels (20W-40W each) with a total power of 80W to 160W and a total 48V voltage system, which will be used to charge our backup battery for swapping with the primary battery after its full discharge.

3	Conventional Motor Controlled System	The e-bike will have a forward motion with the help of a 48V, 20Ah battery and a 1000W motor, which will be controlled using a throttle by regulating the voltage through a speed controller.
4	Chassis Structure	A strong and sustainable chassis with Aluminum Alloy that can carry up to 150 Kg of weight. The parameters of this e-bike will be around Inseam (73-78 cm) length, (170mm) Crank size, (56cm) Center to top length, (110cm) Body length, (24 inch E6) Rim, (40mm) Tire,(1947.79mm) Circumference of the wheel,(62.2cm) Wheel diameter.

Table 6: System Level Specification Of Approach 3

- **Component Level:**

Sl No	Component	Model	Component Description	Specifications	Components Level Specification
1	Lithium - ion battery	WKQX 48V, 20AH	Li-ion battery is used because of its better weight-to-power ratio. Compared to lead acid batteries can energize heavy motors within a short space.	48V, 20Ah can give (40-55) Km of mileage.	
2	BLDC motor	(Model: GP-D30 F/R/C)	Essentially linear torque(neglecting iron losses), with torque proportional to current and speed proportional to voltage. Placed in the wheel which gives better balance during its movement or dynamic situation.	Rated 1000 Watts	

3	Controller	Vbestlife pu96x5iy cm	Can drive sine wave motors, rectangular motors, and also suitable for Hall motors, can support 36V, 48V, 52V. The drive motor has thicker copper bars, and higher inductance accuracy, smoother starting, and more comfortable riding.	For 36V/48V; the Rated power: 1000W; Max current: is 30A. Can give the speed of 45 km/h	1. Diode- 1N4148 2. Capacitor - 10nF 3. Mosfet - (3N163) 4. Switches 5. Resistors- 1Kohm, 100 ohms 6. Arduino mini / Atmega328 7. Hall sensor - MH177 8. Op-amp - Op77
4	Padel Assisted System			Cadence sensor-based feedback control system	1. Disk with magnets 2. Pedal rotation sensor
5	Throttle	Tbest - Tbestw3 xsp2ugq v	Regulates the voltage which works to speed up or down the two-wheeler.	To control the speed of the motor.	Voltage regulator
6	Solar panel	Rich Solar	80W to 160W of solar power to charge the backup battery for extra range.	48 Volts 200 to 300 Watt panels. (Four panels with 12V, 20W-40W each)	

7	Solar charge controller	MPT-7210A	Converts unstable DC source to stable DC source to charge the battery using solar input. It works as a boost converter as well when needed.	Input Voltage: 12-60V Output Current: 0-10A Output Voltage: 15-90V (48V 20Ah battery to be charged using an array of 3 solar panels in series, each having 12V 65W to 100W).	1. Diode 1N4007 2. Resistor - 10k ohm, 4.7k ohm, 330 ohm, 1k ohm 4. Mosfet - IRF9630, IRF540 5. Transistor - (BC547) 6. Capacitor - 100uFr

Table 7: Component Level Specification Of Approach 3

1.2.3 Technical And Non-Technical Consideration And Constraint In Design Process

1. Short life Span: Compared to combustion engine motorbikes the expected life of electric bicycles is much lower. On an average motorcycle, life expectancy is about 15-20 years, and on the other hand average lifespan of the battery of an electric bicycle is about 4-6 years.

2. Lack of charging stations: Limited distance before recharging is necessary[27].

3. Lack of Torque Compared to Combustion Engines: One of the main problems with electric bicycles is their lack of torque. While conventional motorbikes are powerful enough to ride up city flyovers and steep slopes.

4. Insufficient lanes in most cities: Even though this is not an issue that is specific to E-bikes but is also true for conventional bikes, the lack of bike lanes is still a big problem in many big cities.

1.2.4 Applicable Compliance, Standards and Codes

● **International Organization For Standardization**

Electrical safety standards are implemented by ISO 13849-1:2015: related to requirements for circuits, batteries, wires, power control, etc. Specified frame and fork test method ISO 4210 Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy, ISO 11451-1.

● **EN(European Norm)Standard**

The Machinery Directive has finally unified the European norm for electric bicycles with pedal assistance up to a top speed of 25 km/h and a top continuous motor output of 250 W(EN15194:2017).

● **USA standard**

According to US federal law an electric bicycle is defined as a two-wheel vehicle with a motor that has less than 750 watts. Any person operating an electric bicycle is not subject to any requirements or laws applicable to motor vehicles, including the Tennessee Financial Responsibility Law of 1977. TN Code § 55-8-302 (2016).

● **Standard Practices In Bangladesh**

According to regulation 74, sub-regulation 1, clause (a), sub-clause (i) electric vehicles having motor power not more than 5kw do not fall under any regulations of registration. 40/48. Since we are designing a modified bicycle, we will prioritize the safety of the rider and we can modify the aerodynamics of the bicycle for better performance. Such as, designing a shield for the motor and the battery for heat protection.

1.3 Systematic Overview/Summary Of The Proposed Project

After going through the literature review and analyzing the stakeholders requirements we have come to the conclusion that we need such a type of system which is based on a regenerative braking system that is an effective method for enhancing the dynamics of electric bikes and extending battery life.

The regenerative braking system produces energy by using the drive motor which is idled during braking time. Some energy is recycled at the time between starting of the braking process and stopping of the vehicle. Due to the fact that the regeneration is applied to the vehicle in motion, firstly, the motor must be driven during the simulations. After we obtain a simulation result of the whole system we have to measure similar parameters and test out the accuracy of the prototype that we build. As we are implementing a regenerative braking system here we need a bidirectional brushless DC motor (BLDC) to achieve our objectives. here are some key points based on which we can describe our system overview:

a. **Drivetrain of an electric bike:** We know, an electric bike has a very simple and straightforward drivetrain than a four-wheeler vehicle. It usually involves an electric motor and the mechanisms that lead the wheels forward. In our system, we have used a BLDC hub motor which will be integrated in the wheel of the bike that directly drives the wheel and thus removing any friction loss that could be created due to a chain drive system throughout the process. The main source of power here is a 48v 10Ah lithium-ion battery which feeds power to the 48v 1000 watt hub motor that runs the bike. To help regulate the speed of the motor and control the braking mechanism we will use an overall controller which will also direct the backward flow of current from the motor to charge the battery.

b. **Control unit:** The control unit is the core system of this overall project, which controls the string of each moving part and signal. In the time of using the braking system, this unit sends a signal to the motor to slow down the ebike. Hall sensor, Driver Regulation circuit, Inverter circuit all are interconnected to collect and act according to the throttle and braking signal. PWM signal, Hall sensor, Driver regulation circuit all provide signal to the six MOSFETs inverter circuit and this inverter drives the motor according to that.

c. **Regenerative braking system:** The system helps to generate electrical energy from the back emf of the vehicle. Basically, it uses the signal of the motor and works while the torque is in the reverse direction. The main theme of this part is to store the energy that is usually lost in the form of heat and friction. Moreover, parallel RBS (Regenerative Braking System) is based upon a mechanical system and activates both the friction and regen system at a time, which leads to comparatively high losses converting electrical energy.

d. **Backup charging system:** For the backup purpose PV panel is our main choice to serve the requirements. In this scenario around 200W-250W solar system is our requirement for charging up the battery. Two (12-24)V, 200W-250W solar panels need around 4.8-5.9hrs of peak sun to charge 48V, 20Ah of battery.

1.4 Conclusion

This design is made with the goal of designing and building an electrically assisted bicycle for the city setting. It is a concept aiming to produce a better and more adaptable mode of transportation. The relevance of the system is clear from the preceding explanation in order to design a flexible cost effective control circuit with a regenerative braking system for the motors in electric bikes.

Chapter 2: Project Design Approach [CO5, CO6]

2.1 Introduction:

In this chapter, the main theme is to discuss the multiple approaches we are about to make for our proposed project. The workflow of the system which defines the overall concept of how the system will act under different conditions. Moreover, this portion also talks about the functionalities and requirements of the overall system. The approaches will be made based upon the requirements, specifications and constraints.

2.2 Identify & Describe Multiple Design Approach:

2.2.1 Design Approach 1:

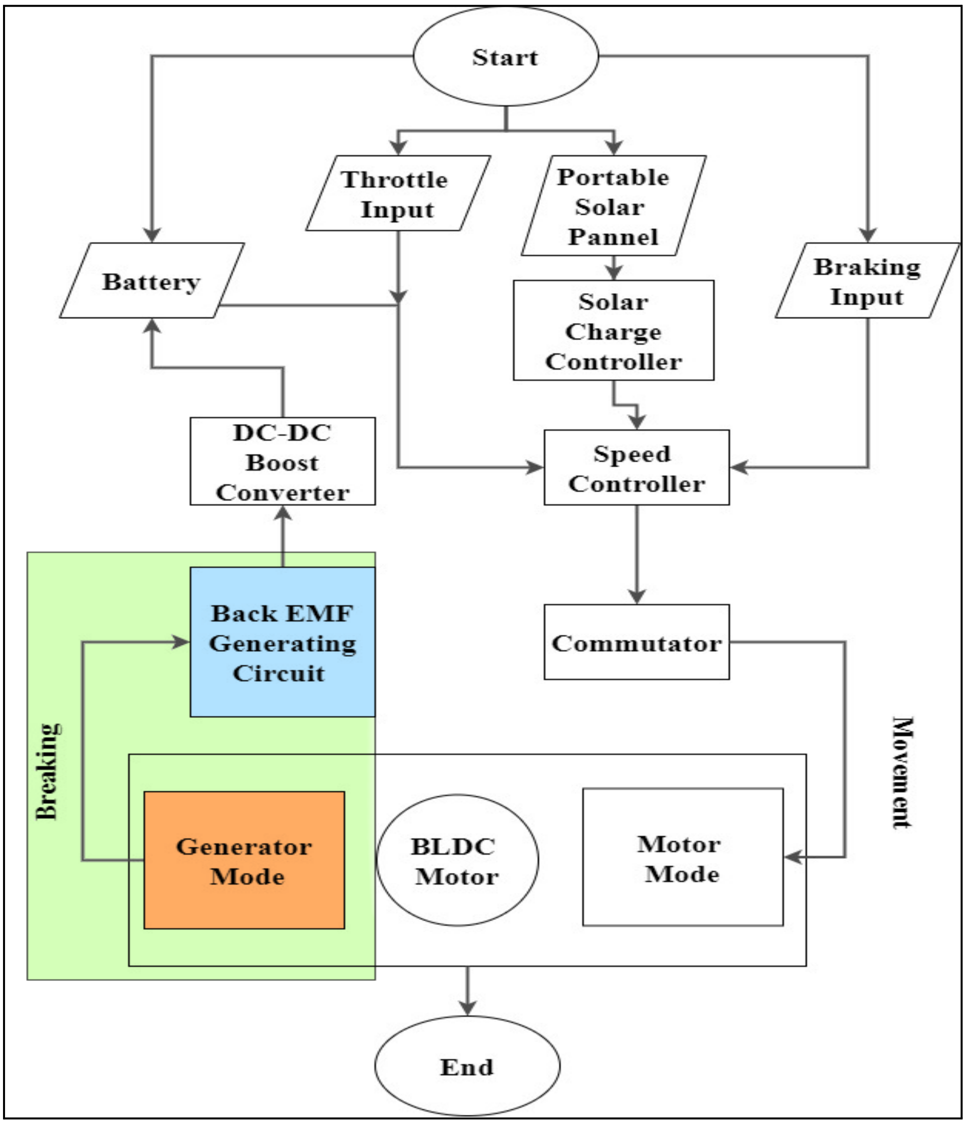


Figure 1: Approach 1 Design Flow Chart

In the first design approach we will try to implement and design an appropriate motor controller/driver that enables regenerative braking to store some energy back to the source and include a portable-sized PV cell for extra power generation for peripheral devices(Optional system).

In order to solve our issue of traffic congestion and transportation time delay, which can be implemented in a bicycle to modify it into a cost-effective E-bike. In this system, there will be an integrated hub motor(BLDC/ PMDC) at the rear of the bike which will be controlled by a processing unit or controller. It will have a Li-ion battery pack as the primary source of power. The controller will control the speed of the motor by taking the throttle input from the rider. The controller will also be able to feed energy back to the battery by enabling the back EMF (Electromotive force) generated by the DC motor. Usually, when the motor is operational, it uses electrical energy from the battery(Li-ion) through the controller to convert it into mechanical energy and rotate the wheel. But when no throttle (voltage regulator) input is given and the bike is decelerating, the motor then can generate energy by wheel rotation (mechanical energy) and convert it into electrical energy.

As all bidirectional motors can generate electricity, we can generate some electricity using this principle. When the user presses the brake pad, we can make the controller voltage supply 0v by triggering the controller and the motor will automatically be in generation mode. Because of the inertia of the wheel, the motor will still be spinning and as the motor's generated voltage is higher than the controller supply, the motor now will be generating back EMF and allowing reverse current to flow back to the battery through the controller while the motor decelerates gradually. This process of regenerative braking can feed back some energy in the battery and increase the overall travel range efficiency of the system. We can also make the power source a bit more efficient by mounting a smaller scaled solar cell on the bike and can generate electricity through a charge controller (Boost converter) to charge the battery or peripheral devices(Mobile phone). This is how we can design the overall workflow of this system to implement a motor controller/driver system with regenerative braking, in order to gain some extra travel range over regular E-bikes.

2.2.2 Design Approach 2:

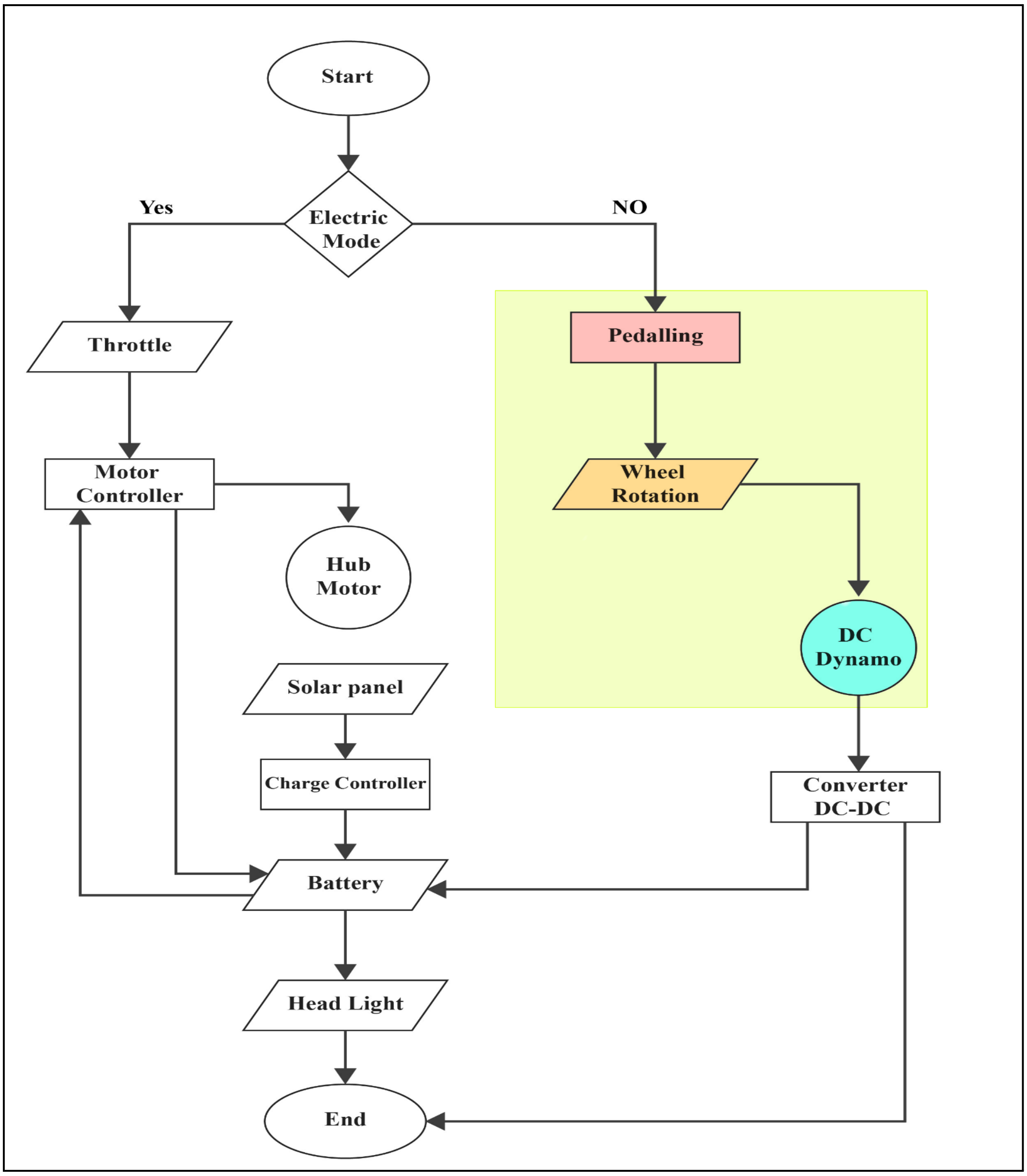


Figure 2: Approach 2 Design Flow Chart

In the second approach we will try to attain the same goal with a different design. Similar to the previous design a speed-controlled integrated hub motor is the main mechanical driving force of the bike here as well.

The speed will be regulated by a throttle in the handlebar. The e-bike will have a Li-ion battery as the main power source which can be charged through any power outlet by a default charger. There will be a BLDC (Brushless DC motor) controller/driver which will control the speed of the rear motor with the help of a throttle(voltage regulator) input from the rider. Here we want to increase the efficiency of the travel range of the battery (Li-ion) by adding a small-scaled DC motor as a dynamo and integrating it into the front wheel of the bike. This overall driver/control system here will include a small portable solar panel and a DC dynamo (motor) to generate some electricity and feed power to the main battery or a peripheral battery for running headlights and indicator lights or charging phones as well.

We know during cycling, whether we are pedaling or using the electric motor to push the bike forward, a good amount of kinetic energy is generated from the wheels of the bike. If we can harness some of the kinetic energy from the wheel and convert it into electrical energy, we can charge a battery using that energy thus increasing the efficiency of the system. The bidirectional dynamo(DC motor) attached to the bike will rotate with the wheel and generate electricity which will be stabilized and converted with the help of a DC-DC converter and then fed into the battery to charge it. We will also have a small solar cell that can be fitted onto the bike chassis in order to generate some electricity which can also be fed into the main battery through a solar charge controller or can be used as a peripheral source as well, thus gaining some extra power. This is how we can implement multiple external sources to generate extra power for the system and increase the effective range of the E-bike.

2.2.3 Design Approach 3:

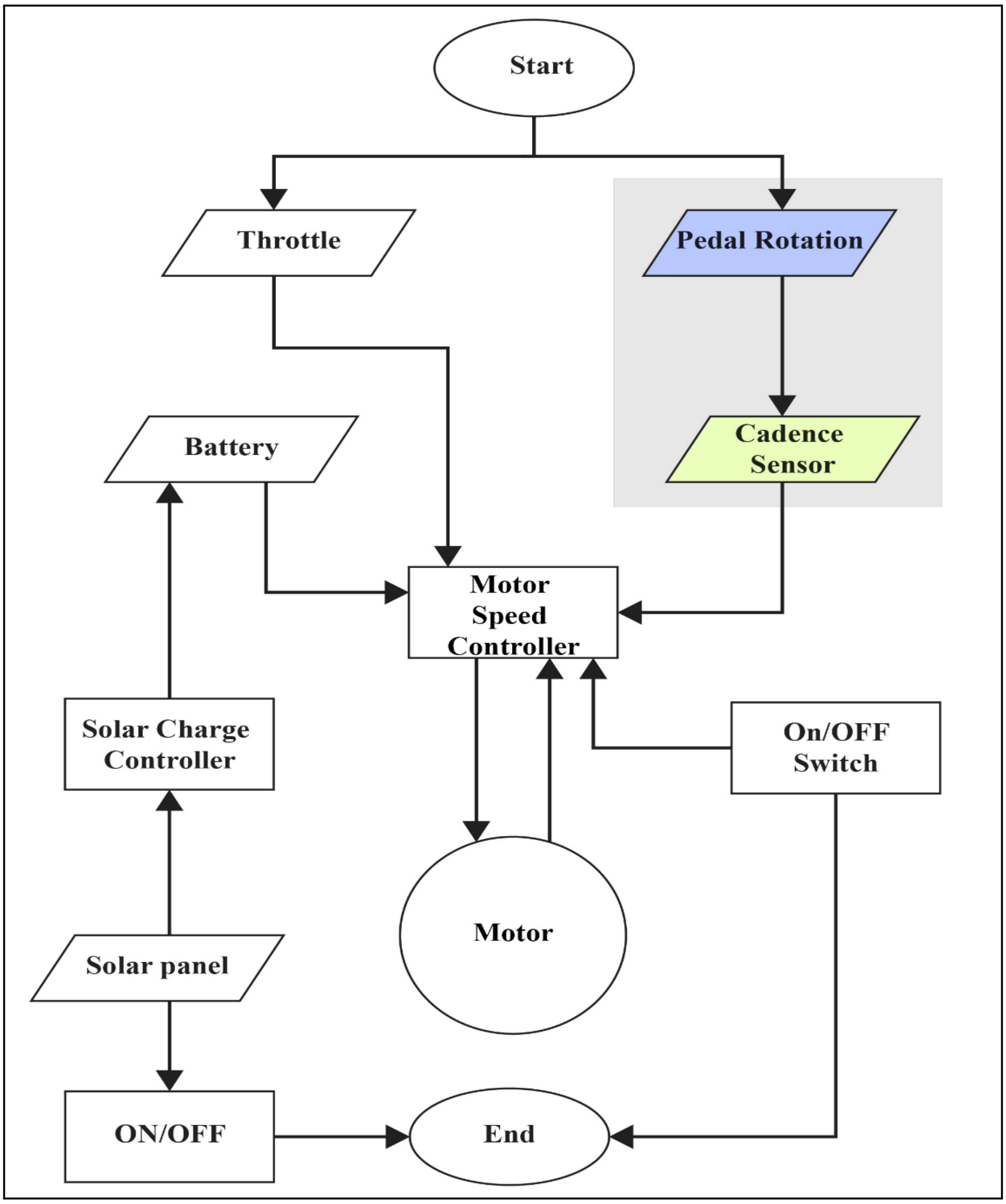


Figure 3: Approach 3 Design Flow Chart

In the third design, we are considering a simple design with a cadence sensor to help with the pedal assist system of the bike. Like the previous approaches, here the main driving force is a rear wheel DC hub motor as well. The motor's speed will be regulated by a BLDC or PMDC (Permanent Magnet DC motor) motor controller which will be triggered by a throttle input from the user.

The main power source is the Li-ion battery pack. This battery pack can be charged from the regular power outlet through a charger or with the help of a solar charger. In this approach, if we consider the system level design, the main contributing factor here is the pedal assist system using a cadence sensor. It is a physical device where a disk of small magnets is attached to the crank arm and every time the rider pedals, the magnet disk goes past the sensor and it sends a signal to the motor controller. This signal is then manipulated and used to turn the motor on through the motor controller at a lower speed to assist the rider with pedaling. This system works as a switching mechanism for the hub motor which senses or counts the rotation of the crank motion and sends a signal to the controller in order to turn on the motor and make pedaling easier for the rider.

Along with the pedal assist system, we can make it a bit more effective and user-friendly by including a small solar panel that can act as a peripheral source of power. We can attach a solar panel at the back of the bike and store the charge through a solar charge controller during the daytime. We can feed this extra power to the main source or use it to run peripheral devices(headlights) by charging a small battery or charging a phone using a solar panel. It will require a DC-DC converter to regulate the voltage generated by a PV panel to make it stable and suitable for the Li-ion battery to charge. This pedal-assist system will help the rider to make pedaling easier and also this system will allow the bike to attain a more effective travel range by using both human force and motor force which uses less power by running at a low RPM speed to help push the bike. With the combination of a cadence sensor-based pedal assist system and a PV panel as an extra power source for the E-bike along with the battery, it can give us promising results in the process of increasing the effective range of the system.

2.3 Analysis Of Multiple Design Approach

Criteria	Approach 01	Approach 02	Approach 03
Power Source Options	This approach has a secondary power source of a solar panel to generate some extra power for the battery.	In this case, we have 2 ways to generate extra power. One is a DC dynamo to feed some charge to the battery through a converter and another one is a solar panel.	This design only has one extra source of power, which is a solar panel similar to the first approach.

Controller Operation	This approach has one controller which can control the forward motion of the motor and can also enable reverse current flow from the motor to the battery through regenerative braking. We also have a solar charge controller as well.	This approach has multiple separate controllers, one for controlling the speed of the motor and another two is converters to charge the battery from the dynamo and the solar panel.	In this approach we have a controller to control the speed of the motor which can take a signal from the cadence sensor of the pedal rotation and use it to generate pedal assist for the bike and Another controller/converter here is the solar charge converter similar to the first design.
Travel Range Improvement	This design approaches 2 ways to increase the travel range of the e-bike. One is with the help of regenerative braking and recharging the battery with the motor's own generated power and the other way is, by charging the battery from solar as much as possible.	This design tries to increase the range of the bike by extra power generated from the solar panel and also with the power generated by the dc dynamo attached with the wheel.	In this approach the attempt to increase the range is with the help of only solar power.
Maintenance	This design requires very less maintenance, as it has less moving parts and braking is mostly done by the controller. So less chance of braking pad replacement.	This approach needs more maintenance compared to other designs. Because it has a dynamo attached with the wheel which is constantly rotating with friction from the wheel. So it is more likely to have braking pad issues and the longevity of the wheel can be hampered as well.	This approach has less maintenance than approach 2. But it will have some degree of maintenance because of the cadence sensor attached with the pedal. It needs to be checked once in a while.

Cost Effectiveness	In terms of cost efficiency this design scores average, as it can achieve performance efficiency but with a more expensive to make controllers.	This design is cost effective, as it can be made using some cheaper components and also can perform well enough.	This design is also very cost effective in terms of the components used in total to make the system work.

Table 8: Multiple Designs Comparison

2.4 Conclusion:

By analyzing all three approaches, we can sum up the whole concept in terms of the theoretical point of view. Regarding approach-01, the main source of power which will run the whole system is a 48V and 20Ah battery. The purpose of this approach is to harness the energy from the braking system. A certain amount of energy is possible to harness from the braking system, instead all losing this amount in the form of friction and heat. The addition of this extra energy will pile a bit of energy in the storage and will help increase the mileage. The controller of the regenerative braking system is different from the conventional controller, as it works only when the voltage is decreasing. In approach-02 the main source of energy is the same as approach-01 and for the peripherals, there is an additional dynamo system that will generate a certain amount of voltage with the rotation of the wheel. Lastly, approach-03's power source is a 48V, 20Ah battery and the difference from the other two approaches is mainly this system is based upon a cadence sensor, which basically senses the motion of the wheel to start the motor and makes the ride easier. In terms of a backup power source, there is a solar panel that will provide a bit of extra energy extracted from the solar energy.

Chapter 3: Use Of Modern Engineering And IT Tools [CO9]

3.1 Introduction

A complicated engineering project must be developed and tested for viability using the ideal modern engineering / IT tools. We had to use one tool during the project's circuit construction phase to research and validate the concept. Next, we used a few technical tools to set up the prototype.

3.2 Select Appropriate Engineering And IT Tools

3.2.1 Software Tool Selection

IT Tools		Specification (version)
1	Matlab Simulink	Matlab r2018a, r2020a

Table 9: Selection Of Modern It Tools

3.2.2 Hardware Tool Selection

Tools		Model
1	Lithium-Ion Battery	WKQX 48V, 20AH
2	BLDC Hub Motor	(Model- GP-D30F/R/C)
3	Hub Motor Controller	SKU283119059_BD-127359 2917
4	Throttle	Tbest - Tbestw3xsp2ugqv
5	Regenerative Braking System Controller	GW-C9
6	Solar Panel	Rich Solar
7	Solar Charge Controller	MPT-7210A
8	Multimeter	OUYIMEI DT9205A
9	Wheel Stand	Man-made With Metal
10	Soldering Iron	60W

Table 10: Selection Of Modern It Tools (Hardware)

3.3 Use Of Modern Engineering And IT Tools

3.3.1 Description Of Software Tools

1. **Matlab Simulink:** Simulink is a MATLAB-based block diagram that is used for modeling, simulating, and analyzing multi-domain dynamical systems. Its primary interface is a graphical block diagramming tool and block libraries. To implement the system we need to design a BLDC motor control using Simulink. Using simulation with Simulink we can reduce the amount of prototype testing and verify the robustness of control algorithms to fault conditions effortlessly.

3.3.2 Description Of Hardware Tools

1. **Lithium-Ion Battery:** Lithium-Ion battery with ratings of 48V, and 10Ah has a longer lifespan approximately 2-4 years than any other type of Lithium battery which is more suitable for electric bikes. This battery can serve power at 960 watts for 1 hour [38].

2. **BLDC Hub Motor:** A brushless DC electric motor is a synchronous motor where DC current is used for power supply. The permanent magnet rotor follows the magnetic fields generated from switching DC currents to the motor windings, which essentially cause them to revolve in space. With the help of the controller, the phase and torque are controlled by adjusting the phase and amplitude of the DC current's pulses. This motor has the advantages of high speed and torque with instantaneous control, high efficiency with low maintenance, and the ability of high power-to-weight ratio.

3. **Hub Motor Controller:** This controller can drive sine wave motors, and rectangular motors, is also suitable for Hall motors, and can support 36V, 48V, and 52V. The drive motor has thicker copper bars, higher inductance accuracy, smoother starting, and more comfortable riding.

4. **Throttle:** Accelerates the motor by increasing or decreasing the voltage.

5. **Regenerative Braking System Controller:** It is an energy recovery technique in which kinetic energy from a moving object is transformed into a form that can be used right away or stored until needed. When the vehicle is braking, the electric motors recover energy that would otherwise be lost to the brake discs as heat by using the vehicle's momentum.

6. **Solar Panel:** Monocrystalline solar panel is a panel that is constructed with a monocrystalline solar cell. This type of solar panel has more efficiency than polycrystalline solar panels.

7. **Solar Charge Controller:** Converts unstable DC source to stable DC source to charge the battery using solar input. It works as a boost converter as well when needed.

8. **Multimeter:** It is used for measuring the voltage and current during our experiment.
9. **Wheel Stand:** It is made to keep the wheel free for rotation during the experiment.
10. **Soldering Iron:** High voltage of electric supply is used for increasing the temperature of the metal alloy which is used for soldering.

3.4 Conclusion

Many engineering tools that were employed are listed in this chapter along with the specific responsibilities for which they were allocated for. All the tools used because of their user-friendly interfaces, extensive libraries, extraordinary adaptability and availability of the products. In this chapter, we have added the hardware and software tools that we used to build the prototype. For the simulation, we have used Matlab simulink and as for the hardware part, we have added the necessary equipment that we are going to use as well. For building any type of system we need to have proper planning and a clear idea of what types of products we are going to use. The various engineering tools that were employed are listed in this chapter along with the specific responsibilities to which they were each assigned.

Chapter 4: Optimization Of Multiple Designs And Finding The Optimal Solution   [CO7]

4.1 Introduction

In this project, there have been proposed three different designs for the purpose of finding out the optimal approach. The purpose of these three designs is to observe the differences between different segments like travel range, cost-effectiveness and longevity. In this chapter, we will implement the methodologies in MATLAB software, we have proposed in the design approaches. These optimized solutions are the reliability to uphold the effectiveness of these designs in front of the stakeholders.

4.2 Optimization Of Multiple Design Approach:

4.2.1 Design Approach 1

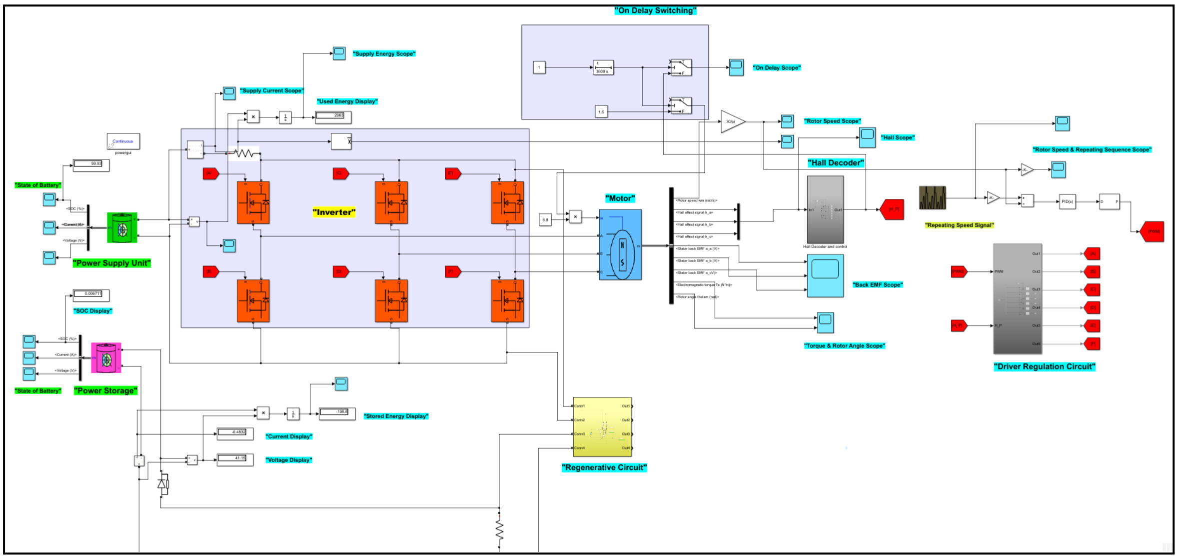


Figure 4: Tentative Overall Regenerative Braking Circuit

In design approach 1, we tried to implement and simulate an appropriate BLDC motor controller that will control the speed of the motor through a throttle on the handlebar and use the regenerative braking system to gain some energy which will be used to charge the battery. This regenerative braking phenomenon will be implemented using the back emf generated in the motor. So while braking, the slowing down of the motor will help generate some energy while also saving some energy by storing it in the battery bit by bit. To test the idea we have done our simulation in matlab simulink by creating a motor controller circuit that can control the speed of a BLDC motor based on a repeating sequence. We also designed an appropriate circuit that receives the back emf from the motor and then a buck-boot controller converts the voltage appropriate for the Li-ion battery to be charged. The simulation approach and results are described below in detail.

Different Parts of Regenerative Braking Circuit

- **Regenerative Circuit:**

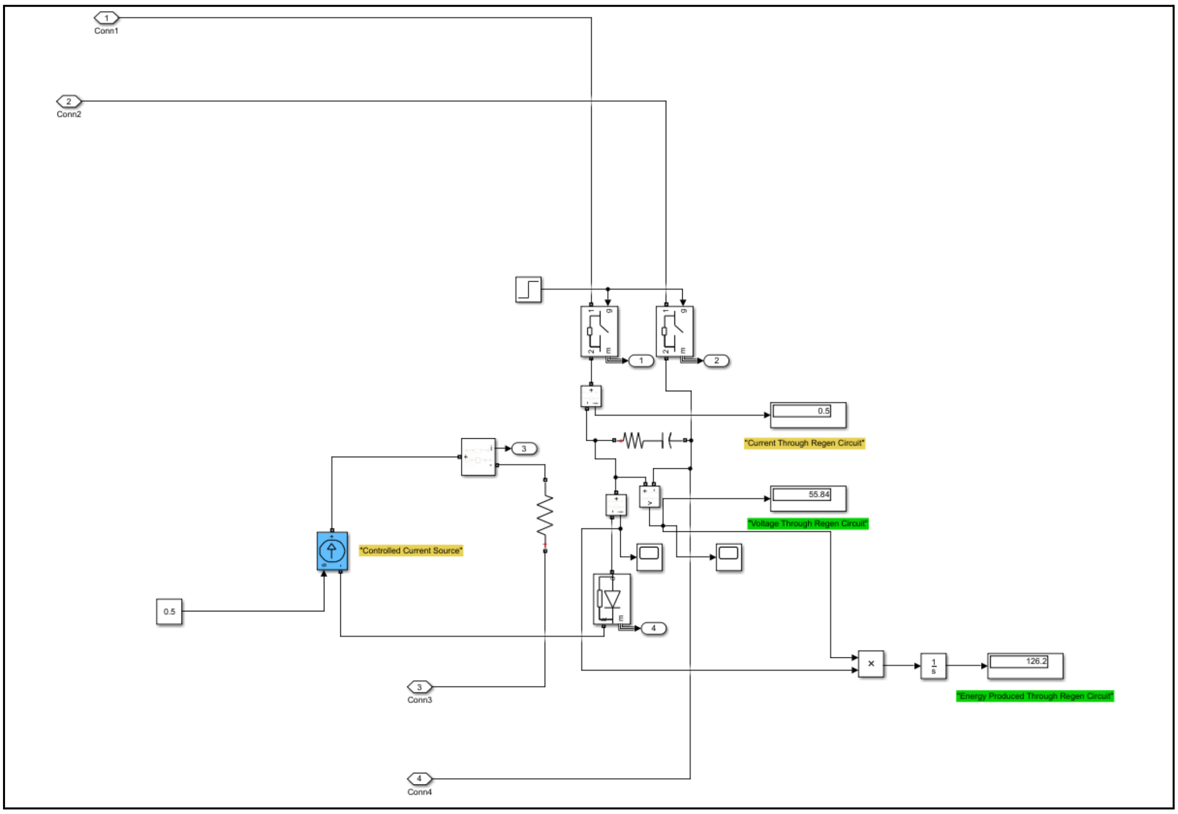


Figure 5: Regenerative Part Of The Main Circuit

Regenerative braking controller enables the back emf to back feed the battery. The supply current passing through the regenerative circuit goes beyond the rated current after a certain period and to overcome this issue, there has been used a current controller circuit. This current controller circuit makes sure that the flow of current remains steady and stable through the regenerative circuit to the battery.

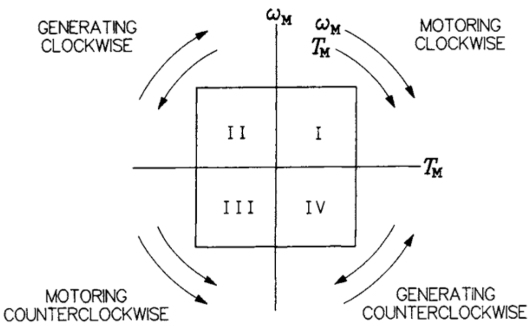


Figure 6: Quadrant Motor Operation

Since the BLDC motor works in four different quadrants, for generating the back emf, it has to work in the second quadrant. For a BLDC motor to operate, the value of the battery voltage has to be lesser than the back emf for this reason we need to use a boost converter to increase the magnitude of the back emf.

- **Motor-Driver circuit:**

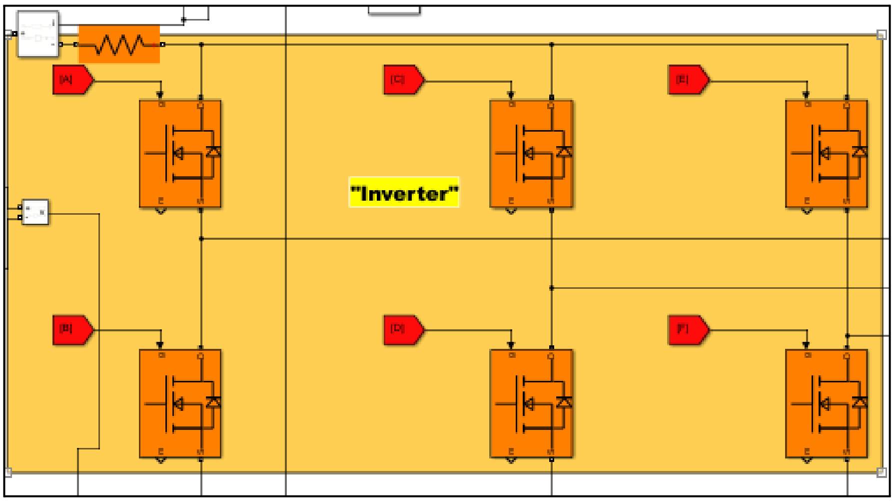


Figure 7: Motor Driver Circuit

In figure 7 we built a driver circuit with a battery pack that acts as an interface between the motors and the control circuits. The motor requires a high amount of current whereas the controller circuit works on low-current control signals. So, the function of a motor driver is to convert the low current situation into a high current control signal that can drive a motor.

- **Switching Circuit**

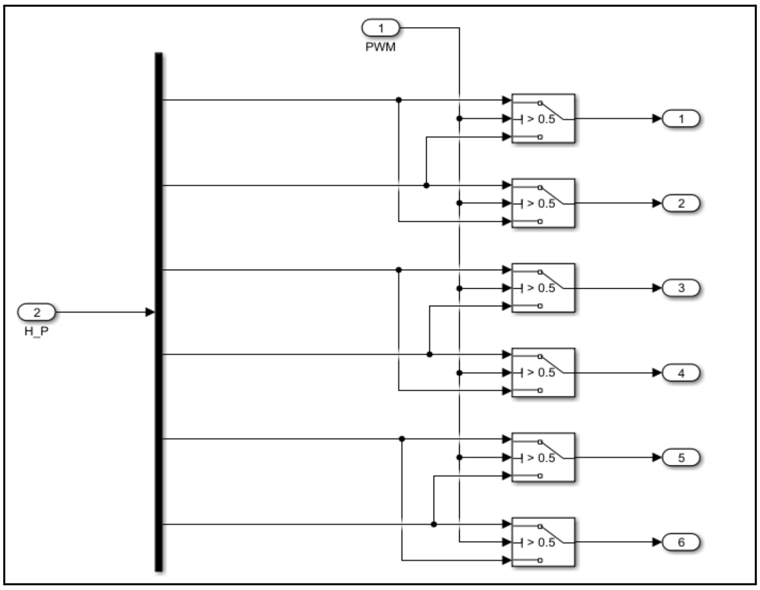


Figure 8: Switching Unit

It takes a hall sensor as an input and also takes the PWM signal to use as a switching mechanism to output appropriate pulses depending on the switching conditions for each signal.

- **Hall Sensor Decoder:**

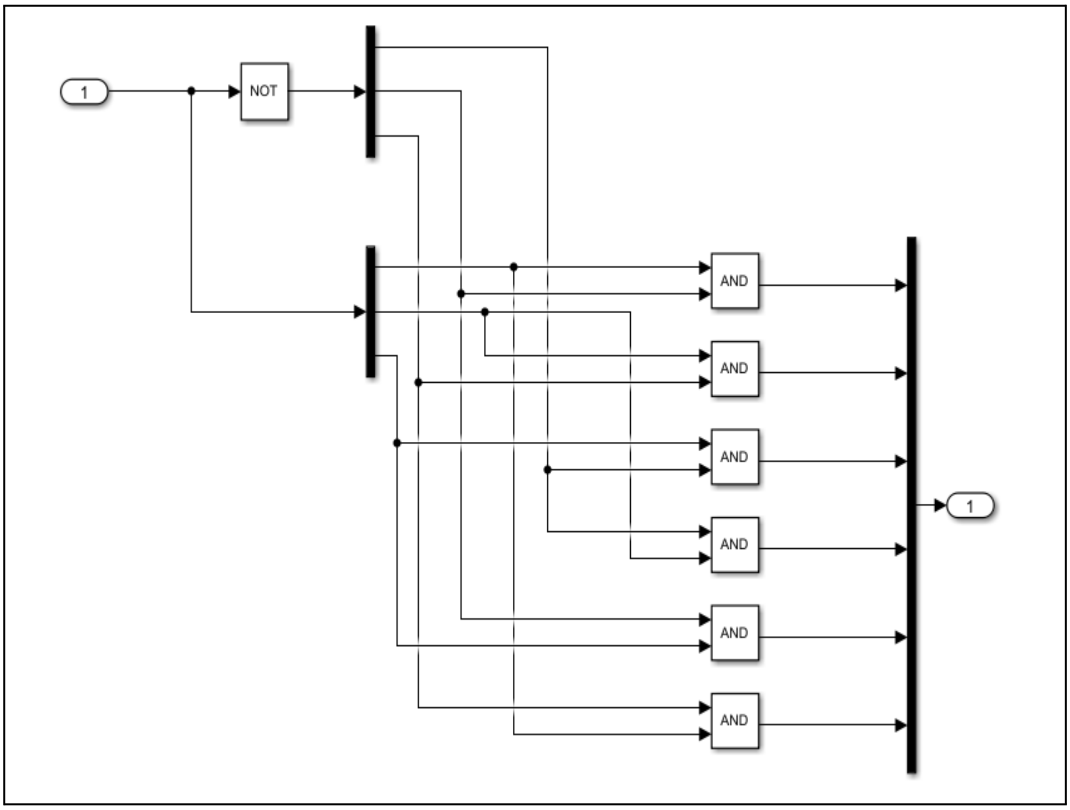


Figure 9: Hall Sensor Decoder

The rotor position was determined by taking the hall effect signal from the bus selector block connected to the motor block. A three-phase BLDC motor had three hall effect sensors to determine the rotor position.

Obtained Graph From the Simulation:

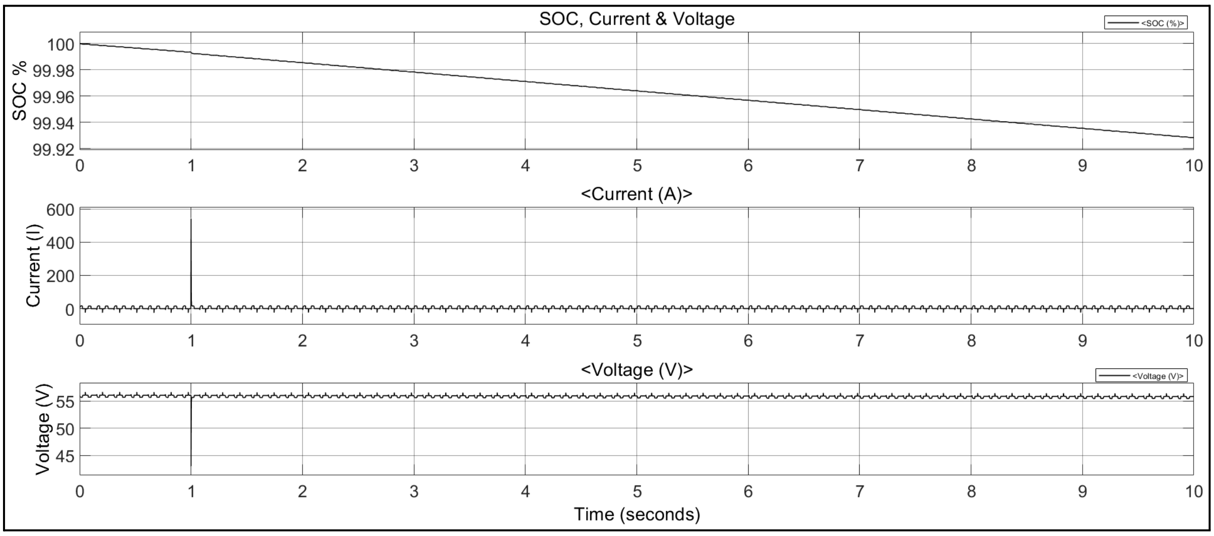


Figure 10: Supply Voltage, Current & Soc Of The Battery
Simulation Results Of Soc Vs Time (S), Current (A) Vs Time (S), Voltage (V) Vs Time (S).

For 10s of supply, the state of charge dropped from 100% to 99.93%. Also, the voltage and current fluctuation are considerably very low.

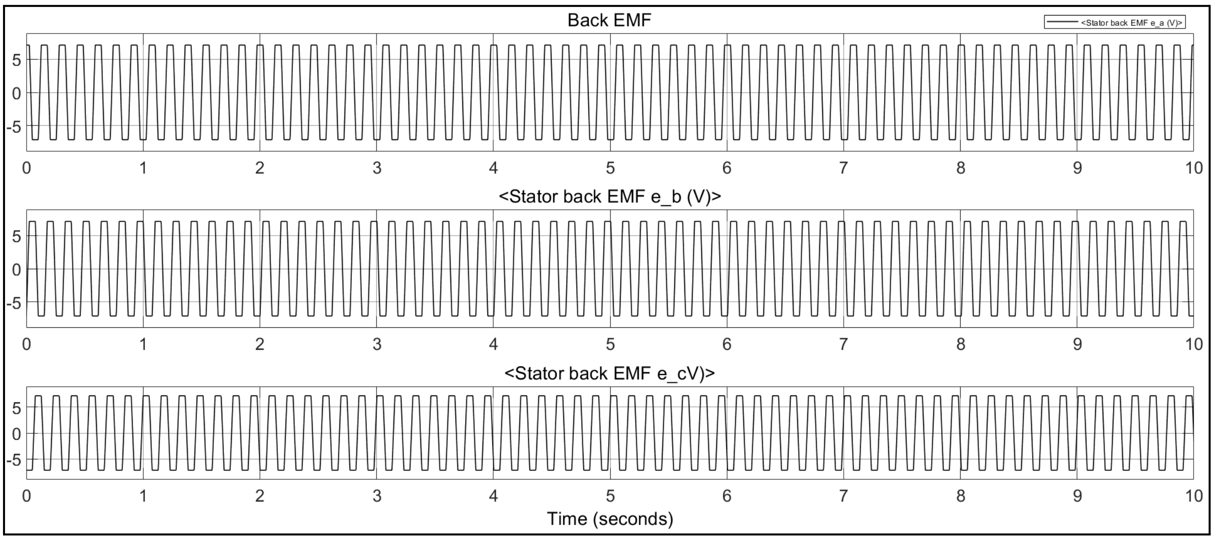


Figure 11: Back Emf Scope
Simulation Result Of Three Phase Stator Back Emf Voltage (V) Vs Time (S)

In figure 11, three-phase back EMF from the motor is shown. From the figure, it can be shown that, when the brake is pressed, the back EMF slope is increasing because of negative acceleration. On the other hand, when the cycle is accelerated, the back EMF slope gets decreased. The graph remains constant between the timing of negative acceleration and acceleration. At that time, the back EMF slope reaches its peak point.

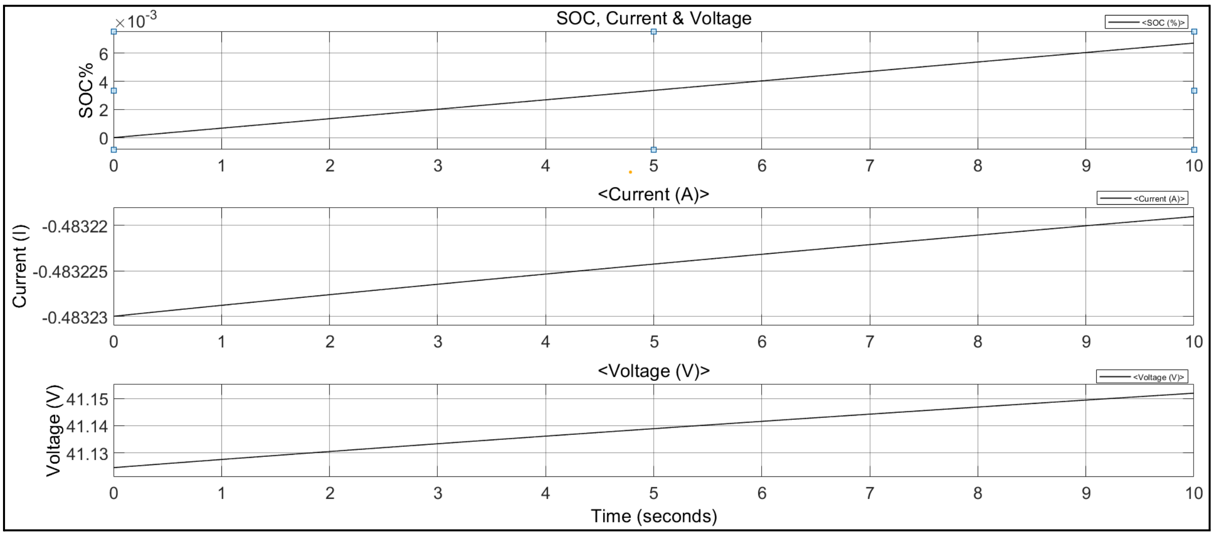


Figure 12: Receiving Voltage, Current & Soc Of The Battery
Simulation Results Of Soc Vs Time (s), Current (A) vs Time (s), Voltage (V) vs Time (s).

In figure 12, receiving voltage, current, and recharging battery percentage are shown. It can be seen that, within 10 seconds receiving current increases in so little amount which can be negligible, and about 0.48322A. Also, the increase of voltage in percentage is also so little which can be neglected as well. Here, the battery again gets recharged at about 0.00671 percent within 10 seconds.

4.2.2 Design Approach 2

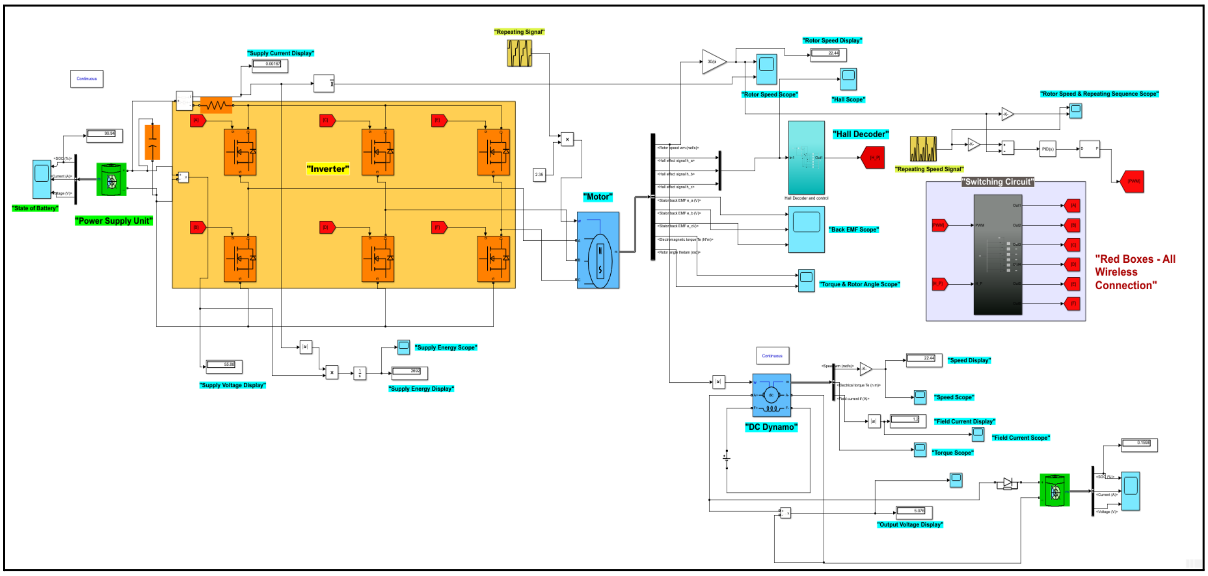


Figure 13: Ebike Simulation With Dc Dynamo

In design approach 2, in a similar manner we designed a BLDC motor controller that controls the speed of the motor. Also here we used a DC Dynamo attached to the wheel, which will use mechanical energy from the motor's rotation speed and supply it to the battery by converting it to electrical energy. At first, by the throttle, the acceleration would be given to the motor and the bike will start to run. When the motor is running, the hall decoder will take the signal of the motor's rotation speed and give it to the DC Dynamo. Furthermore, the DC Dynamo will generate electrical energy and supply it to the battery to be recharged. In this way, the battery will be used to be recharged from the motor's rotation speed using Dynamo. The simulation approach and results are described below in detail.

Subsystems:

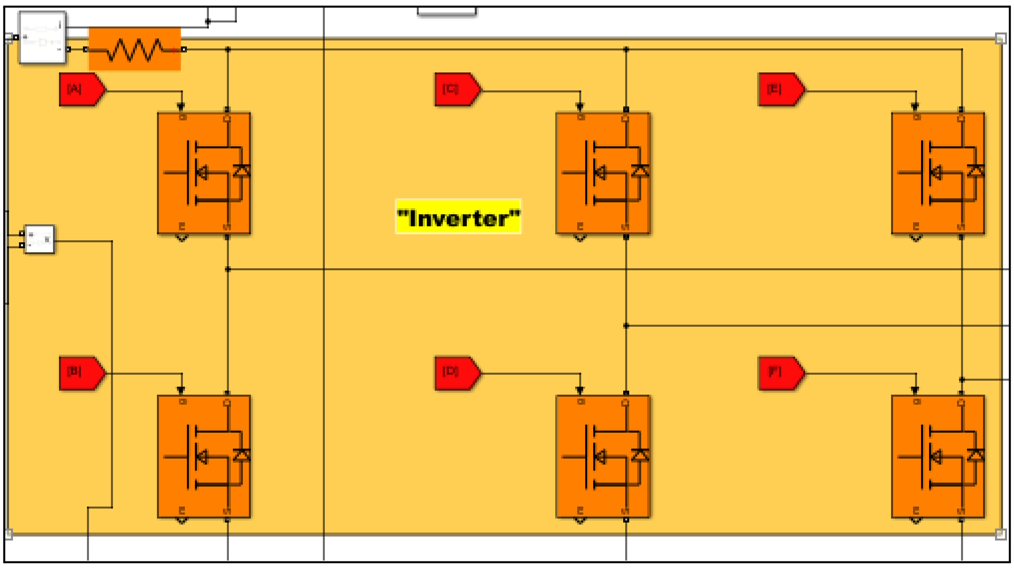


Figure 14: Inverter Circuit/Motor Driver

In figure 15 we built a driver circuit with a battery pack that acts as an interface between the motors and the control circuits to convert the low current situation into a high current control signal that can drive a motor.

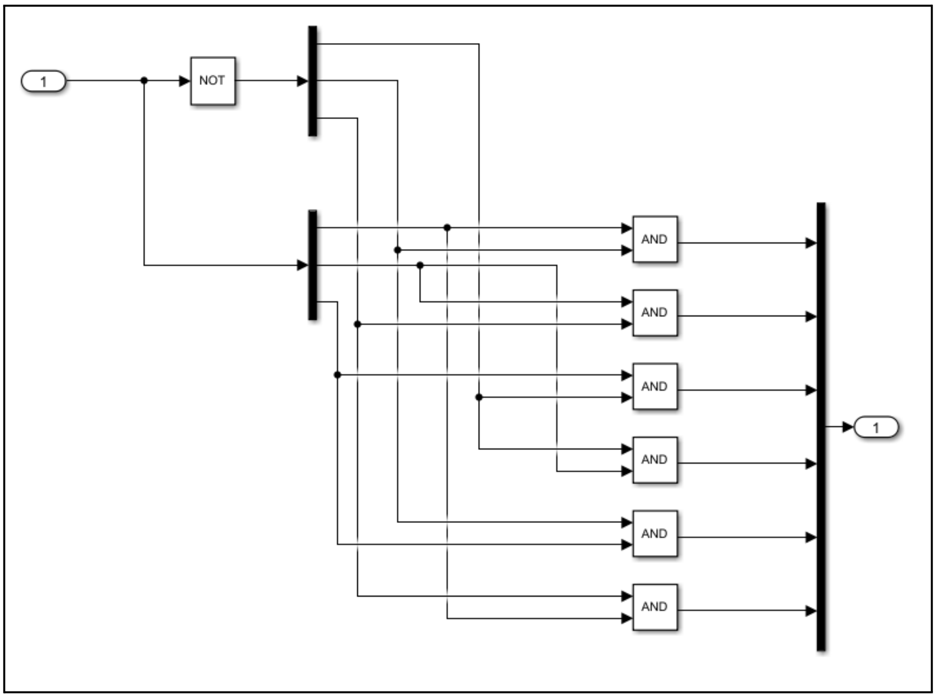


Figure 15: Hall Sensor & Control

The rotor position was determined by taking the hall effect signal from the bus selector block connected to the motor block. A three-phase BLDC motor had three hall effect sensors to determine the rotor position.

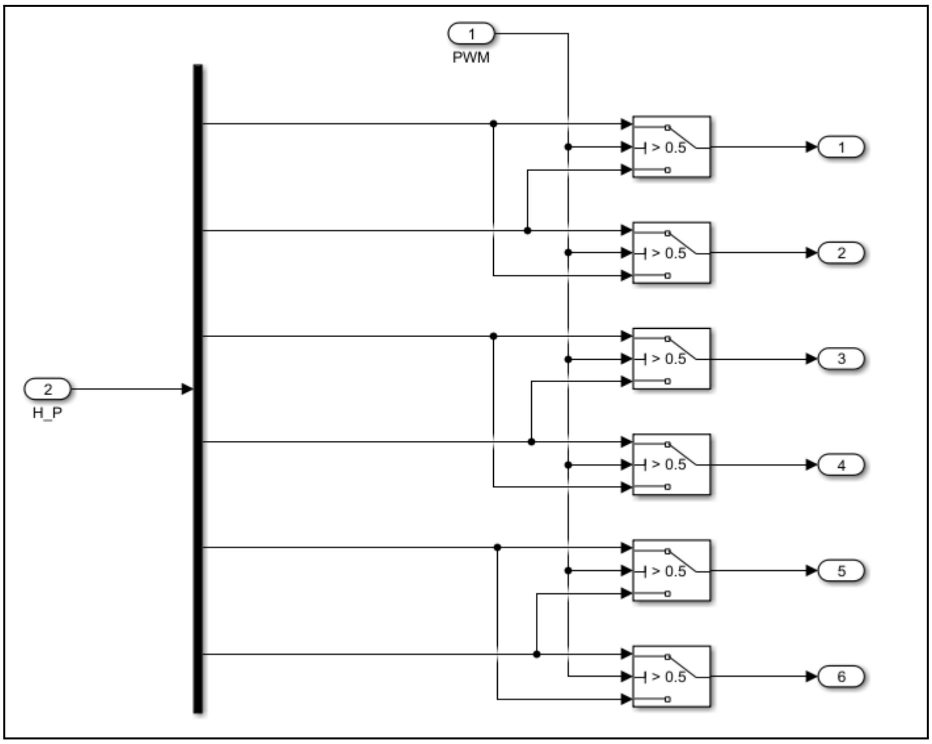


Figure 16: Switching Unit

It takes a hall sensor as an input and also takes the PWM signal, to use it as a switching mechanism to output appropriate pulses depending on the switching conditions for each signal.

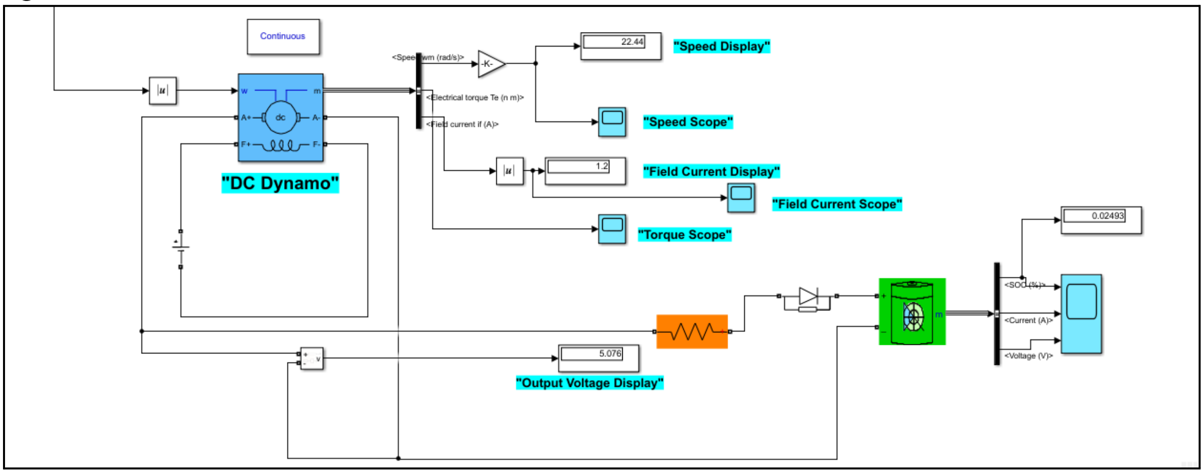


Figure 17: DC Dynamo

DC dynamo produces a very small amount of energy that has been stored in the battery. This segment supplies the peripherals like headlights, displays, etc because of its low voltage supply.

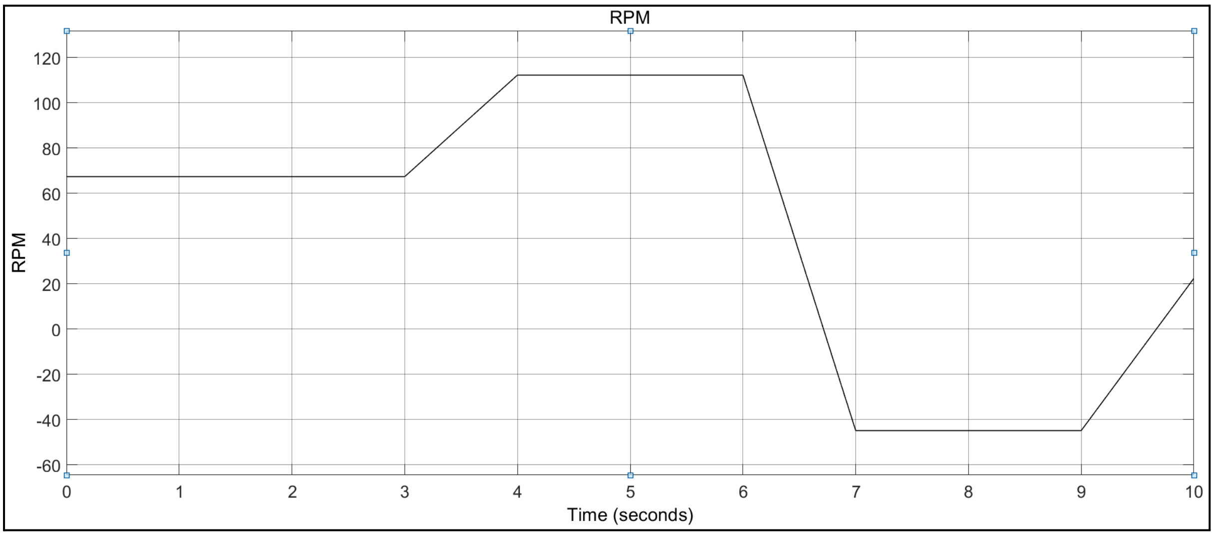


Figure 18: Wheel Speed
Simulation Result of RPM vs Time (s)

In figure 18, the rotation speed of the motor is shown. During 0 to 3 seconds, the rotation speed remains constant at about 67.32 rpm. After 3 seconds, the rotation speed starts to increase up to 112.2rpm in one second and it remains constant again for up to 6 seconds. Then the rotation speed again fluctuates.

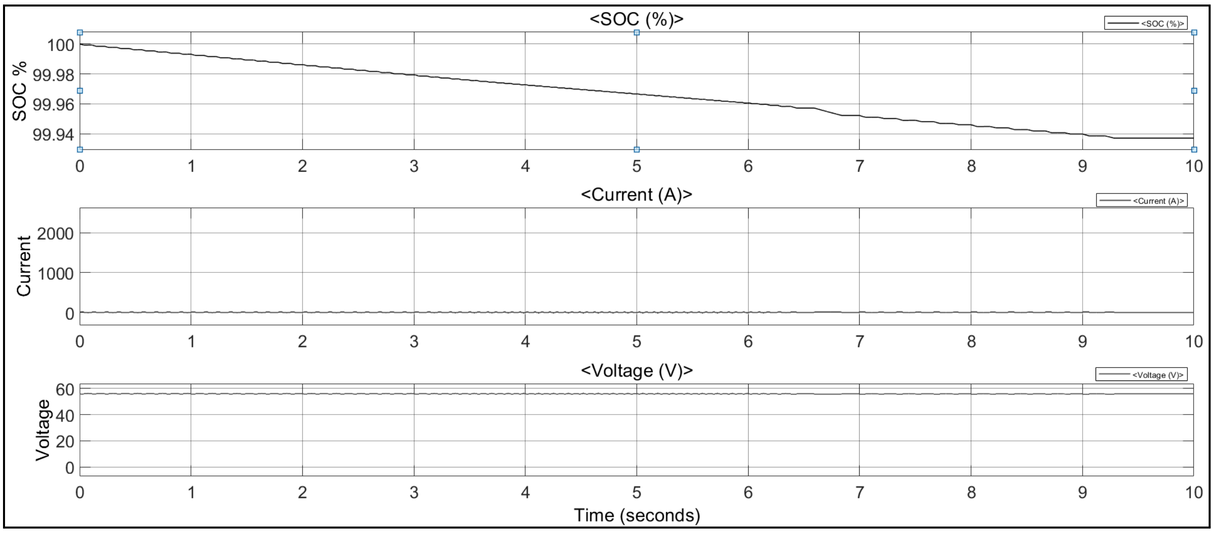


Figure 19: Supply Voltage, Current & SOC of the Battery
Simulation Results of SOC vs Time (s), Current (A) vs Time (s), Voltage (V) vs Time (s).

In figure 20, the supply voltage, current and decreasing battery percentage plot is shown. The supply voltage is about 55.87V and the charge of the battery is decreasing during the 10 seconds runtime. The current and the voltage remains constant with the help of an additional 470uF capacitance.

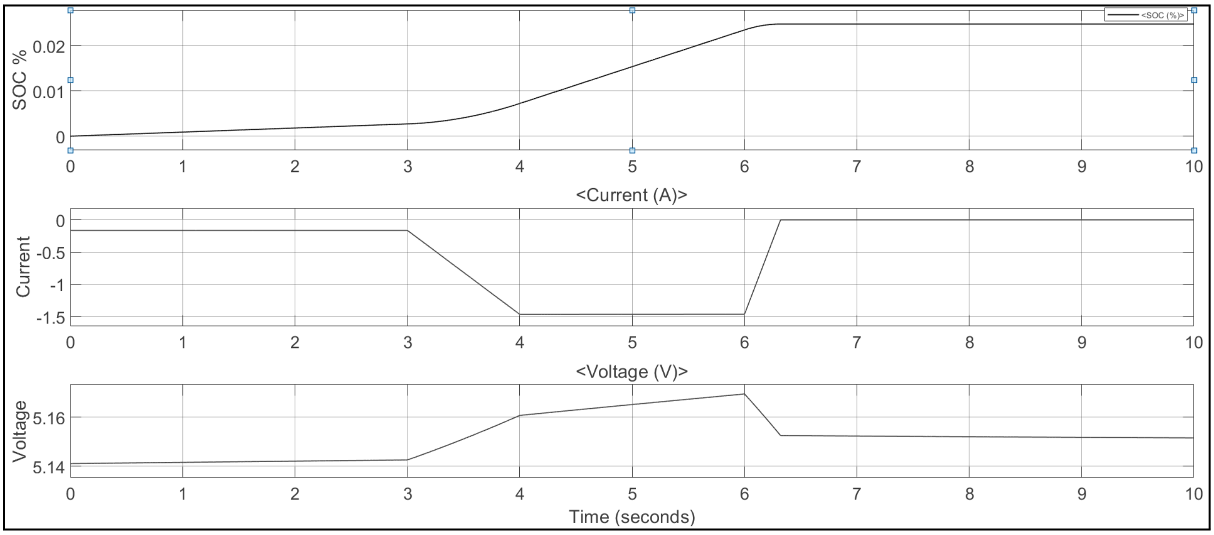


Figure 20: Receiving Voltage, Current & SOC of the Battery
Simulation Results of SOC vs Time (s), Current (A) vs Time (s), Voltage (V) vs Time (s).

In figure 21, the receiving voltage, current, and recharged battery percentage is shown. The receiving voltage is on-average about 5.2V and the current value is close to 0A. And the battery gets charged about 0.02493 percent during 10 seconds of runtime.

4.2.3 Design Approach 3

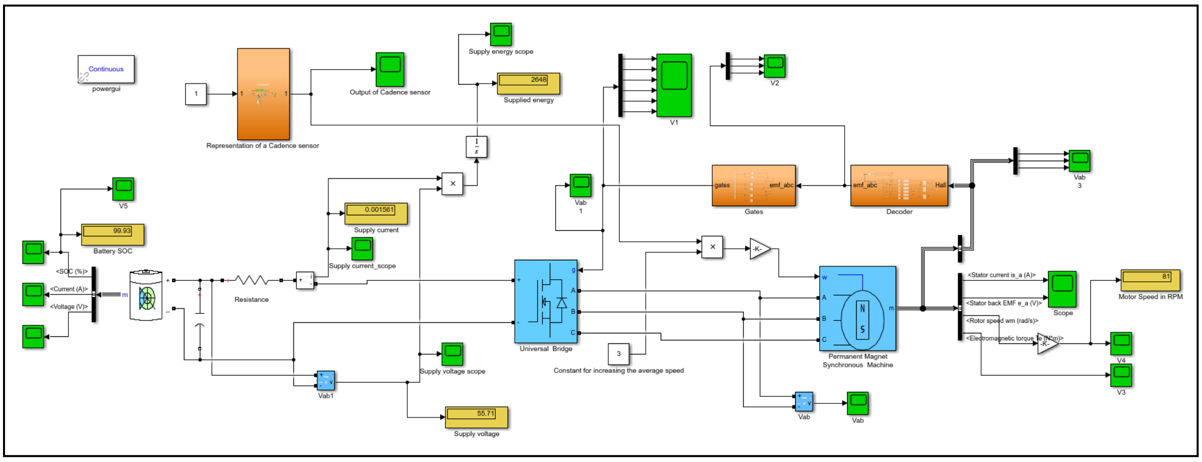


Figure 21: Overall Circuit Design Of The Third Approach.

Here in design approach 3 we tried to implement an electric bike that has a cadence sensor-based pedal assist system. We designed the BLDC motor controller similar to the prior design solutions that control the speed of the motor using a repeating signal. The difference is the repeating signal is created using the pedal assist system. A cadence sensor is attached to the crank of the bike and can be used to sense the rotation of the wheel. So, when the rider starts to pedal the bike the sensor senses the rotation and gives a signal to the motor controller and the motor controller then starts the motor at low rpm to help the rider to pedal the bike. This system overall reduces the effort of the rider and helps cover a longer distance as compared to e-bikes without a pedal assist system. The simulation approach and results are described below in detail.

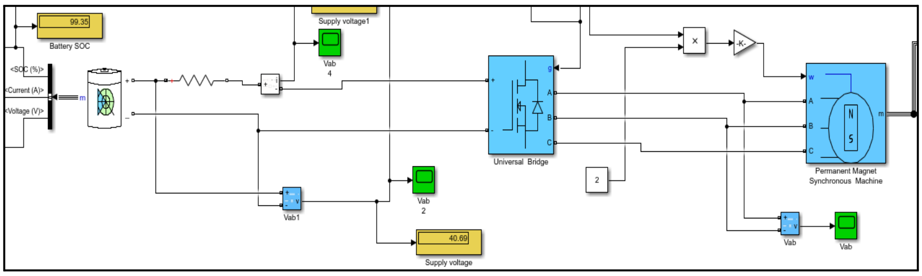


Figure 22: The Battery Is Supplying Power To Run The Bldc Motor Through A Universal Bridge.

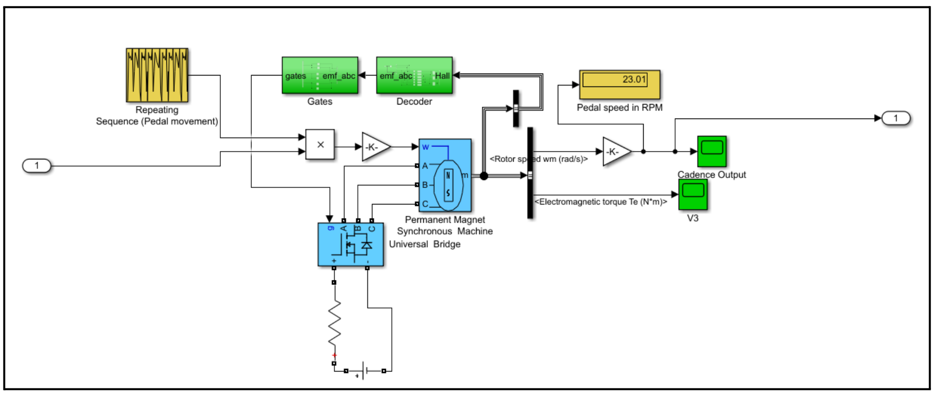


Figure 23: Cadence Sensor-Based Pedal Assist System Representation Using A Bldc Motor.

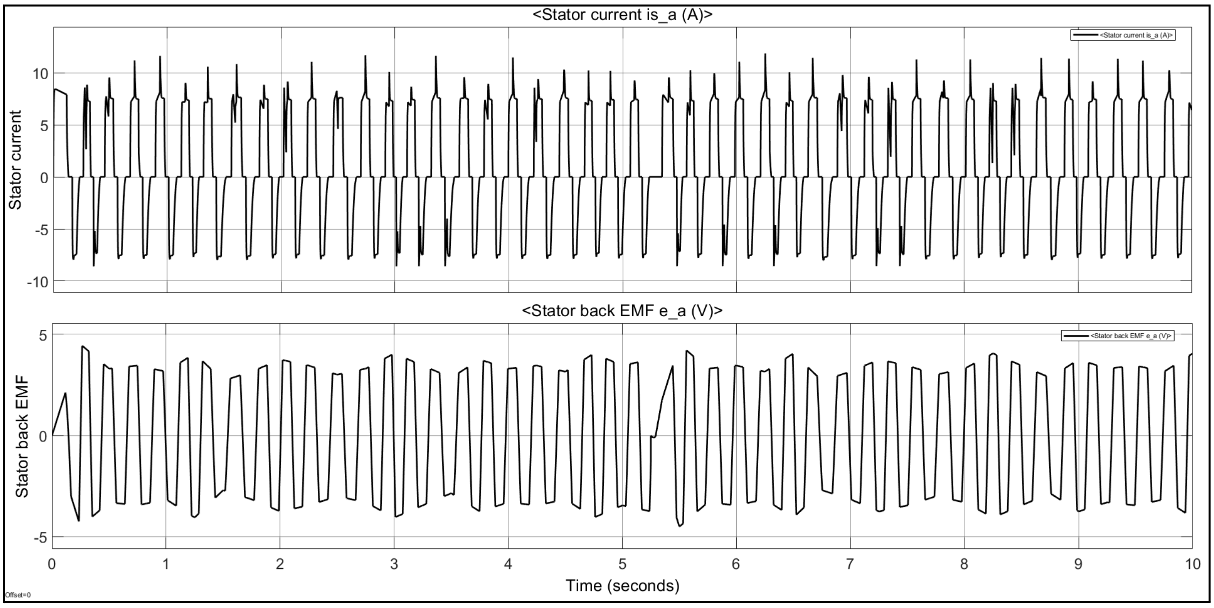


Figure 24: Graph Of The 'a' Phase Of Stator Current And Stator Back Emf (Current Vs Time & Voltage Vs Time)

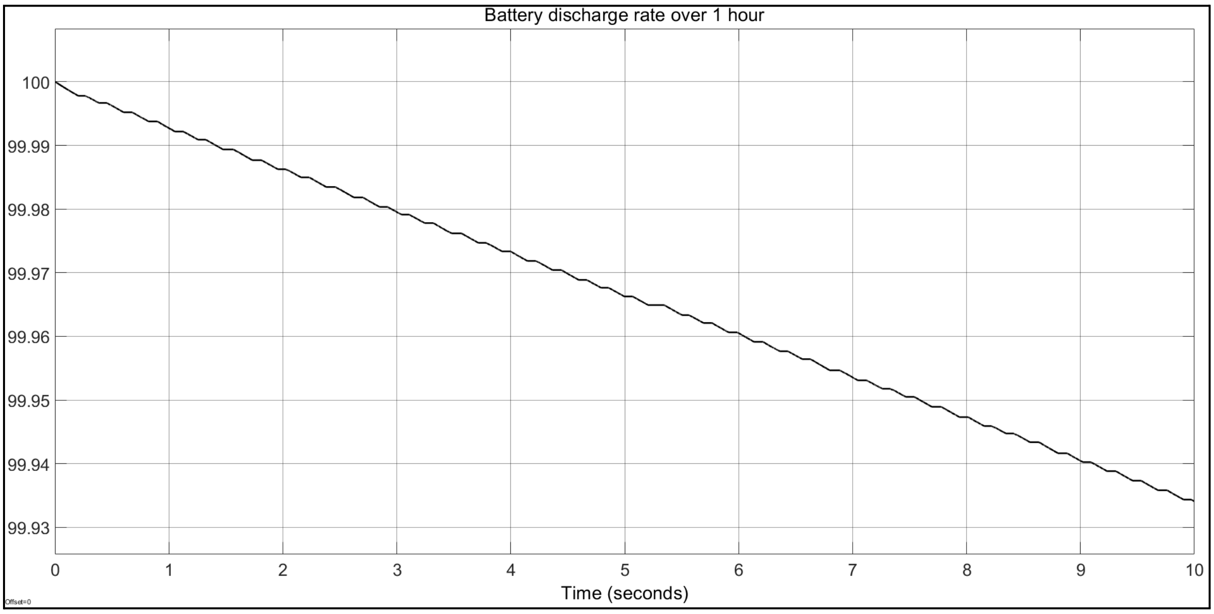


Figure 25: Energy Supplied To The Motor In 10 Seconds Simulation. (Energy vs Time)

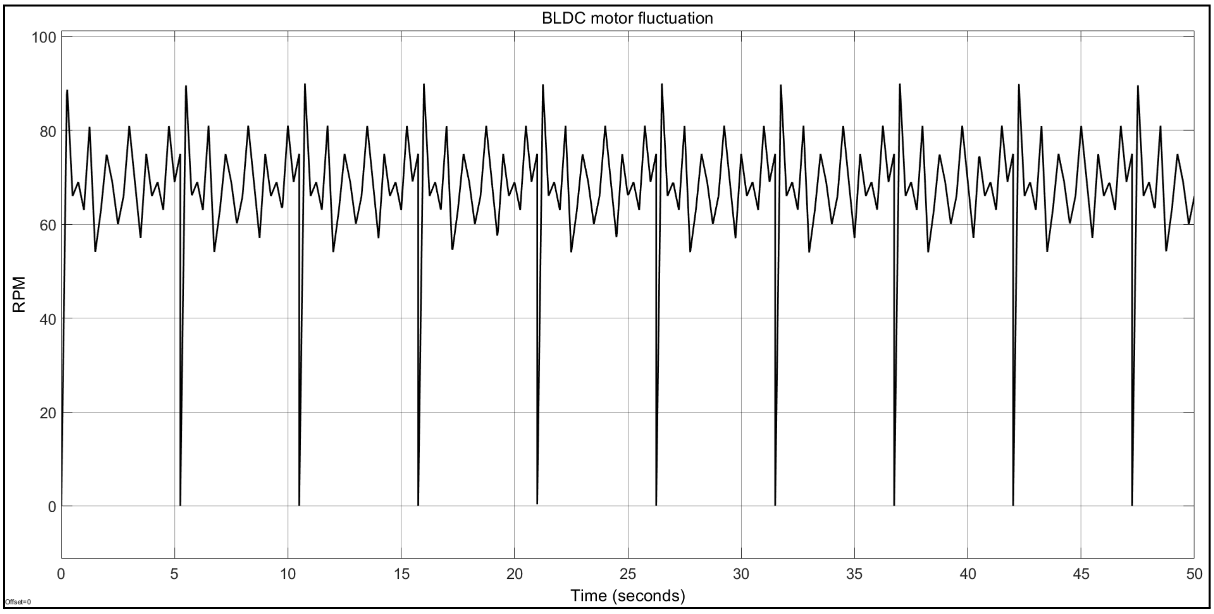


Figure 26: Graph Of The Output Fluctuating Speed Of Bldc Hub Motor.
(Rpm Vs Time)

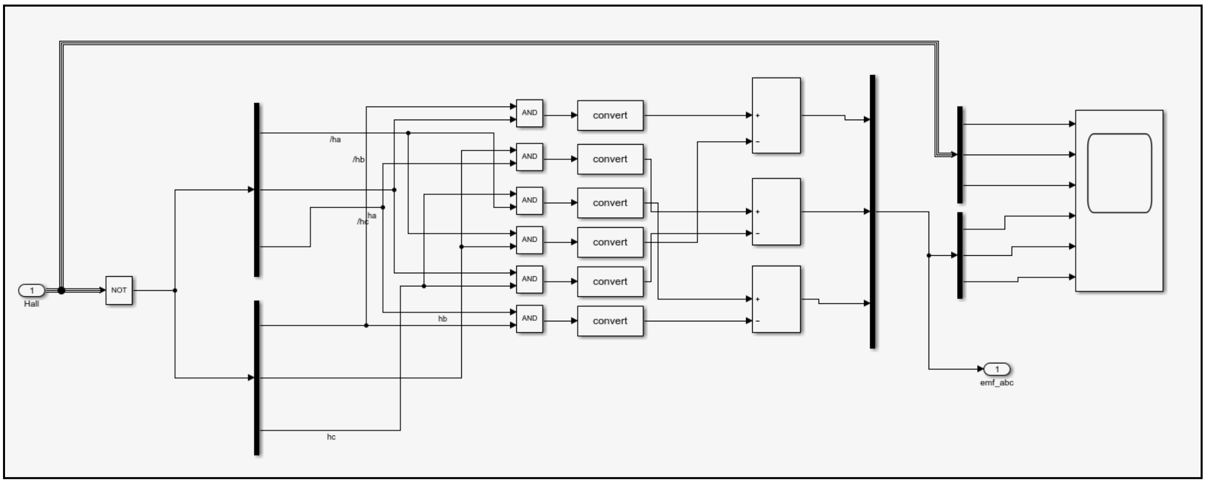


Figure 27: Hall Sensor Signal Decoder.

The rotor position was determined by taking the hall effect signal from the bus selector block connected to the motor block. A three-phase BLDC motor had three hall effect sensors to determine the rotor position.

4.2.4 Backup Battery Charging System Using A Solar Panel:

This solar power system is only for the purpose of backup power. For extracting solar energy there is a need for a solar charge controller to control the flow of the voltage. The solar controller acts as a boost or buck, according to the need for a certain voltage to meet the requirement of the backup battery voltage. The power extraction depends on the irradiance.

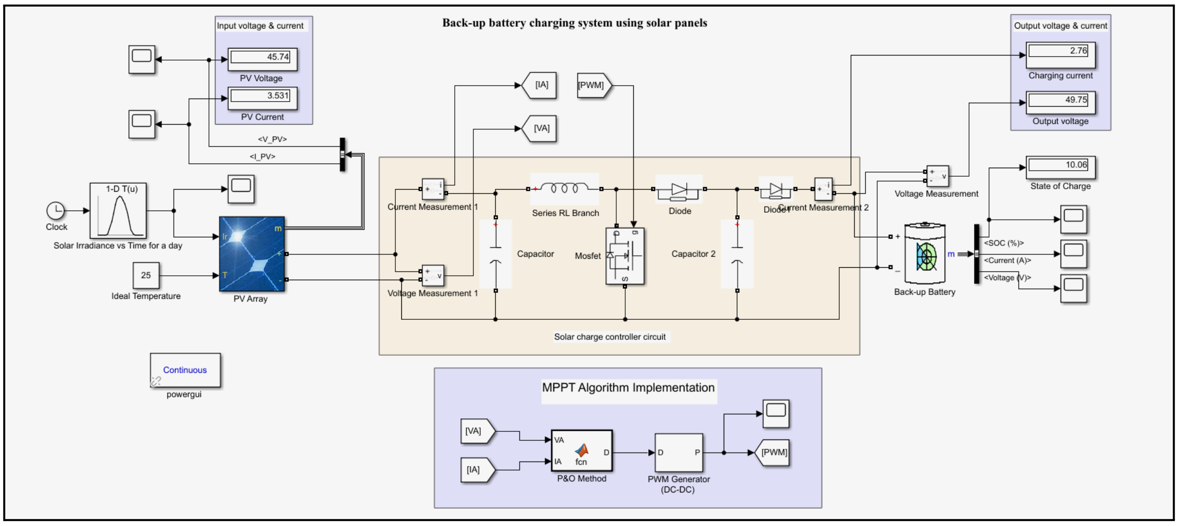
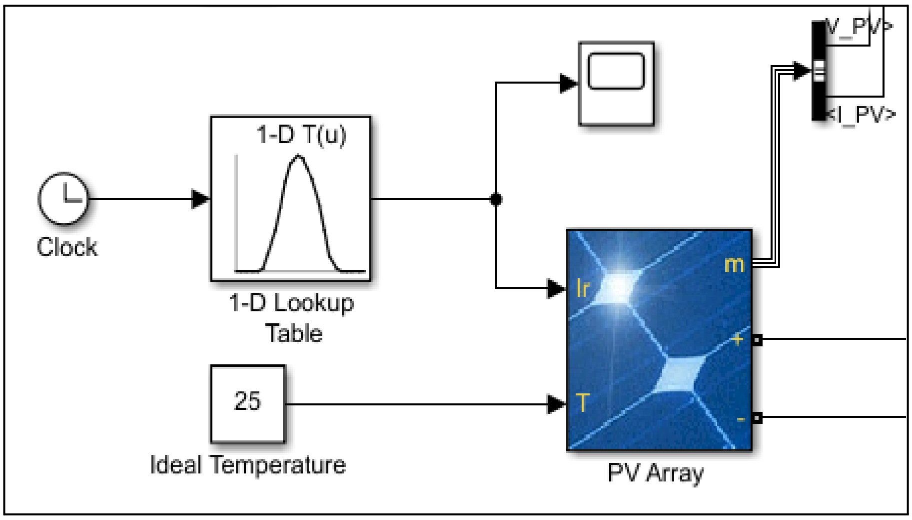
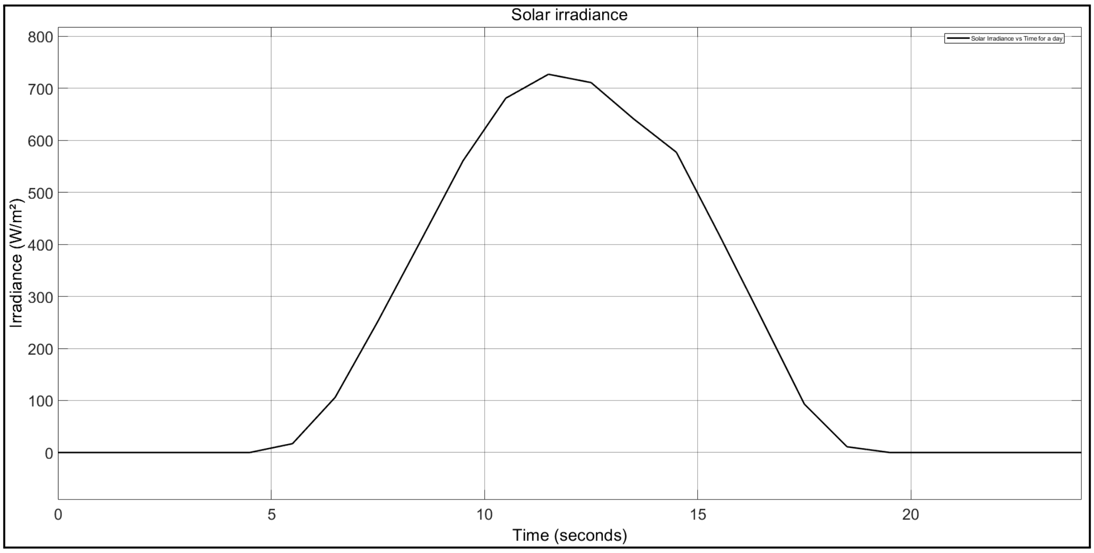


Figure 28: Backup Battery Charging System Using A Solar Panel



(a)



(b)

Figure 29: (A)Input Irradiance Circuit Of Pv Panel Using 24 Hour Data Of The Month Of May (B)Solar Irradiance Data For The Month Of May & Its Circuit.

We took a specific month, May, to get the idea of solar irradiance which is taken as an input to the PV array module. By adding a scope we can check the output of the solar irradiance of that specific month.

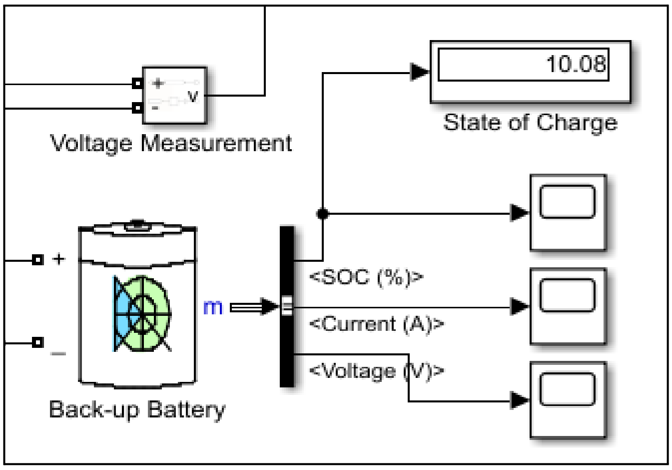


Figure 30: State Of Charge After 24 Seconds Simulation From 10% Initial Stage.

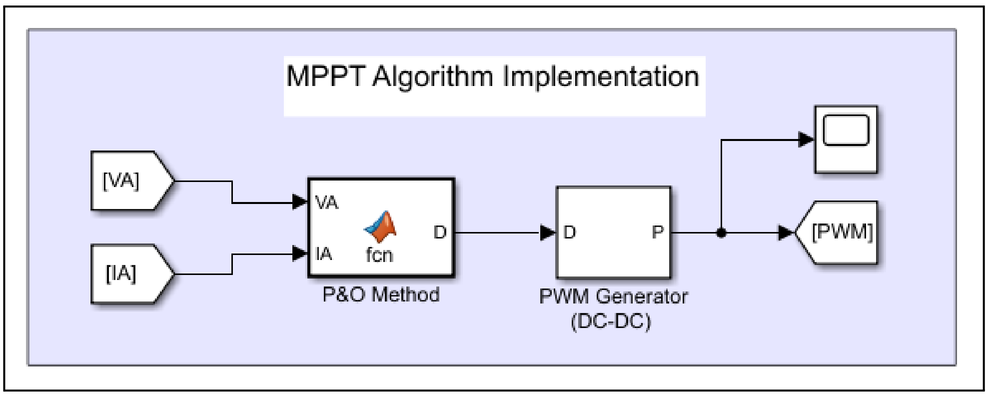
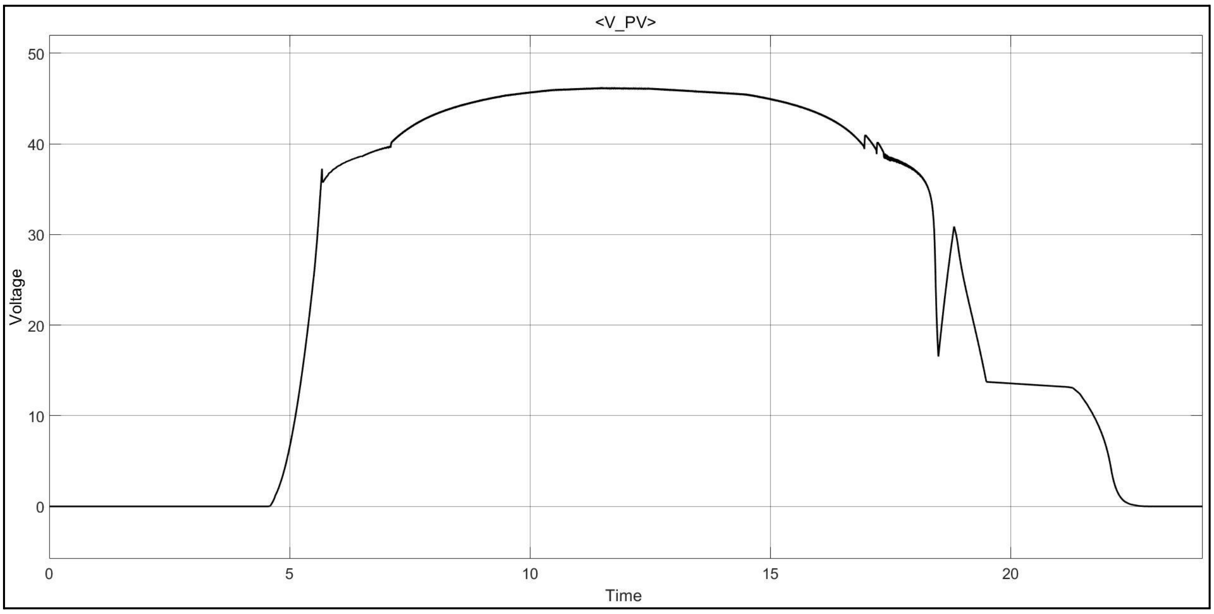


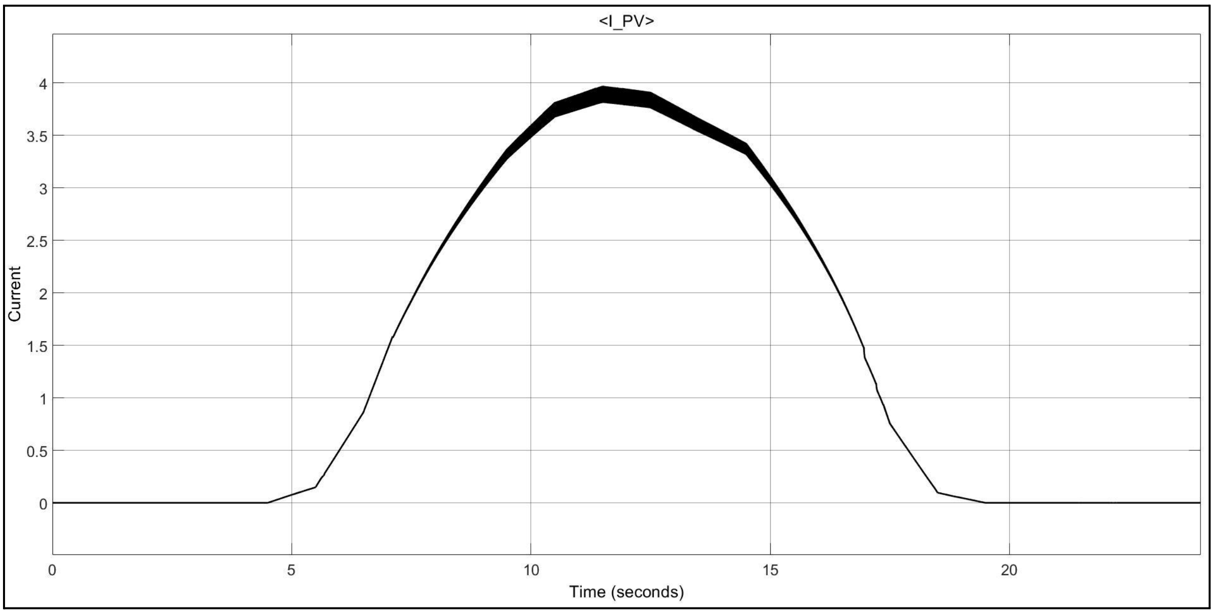
Figure 31: Circuit Implementation Of Mppt(Maximum Power Point Tracking) Algorithm.

Here, the MPPT technique is employed in the control algorithm of the battery charging system that can ensure the maximization of the solar energy transferred to the battery bank from the solar panel. To achieve better exploitation of the PV source we are using a perturb and observe algorithm (P&O) method-based charge controller. We implemented the method by a Matlab code through the function block of the Simulink. It takes the PV panel's voltage and current output and based on the previous values and differences, it changes the duty cycle and supplies a suitable amount of current to the battery maintaining the terminal voltage thus eventually achieving maximum power point tracking.

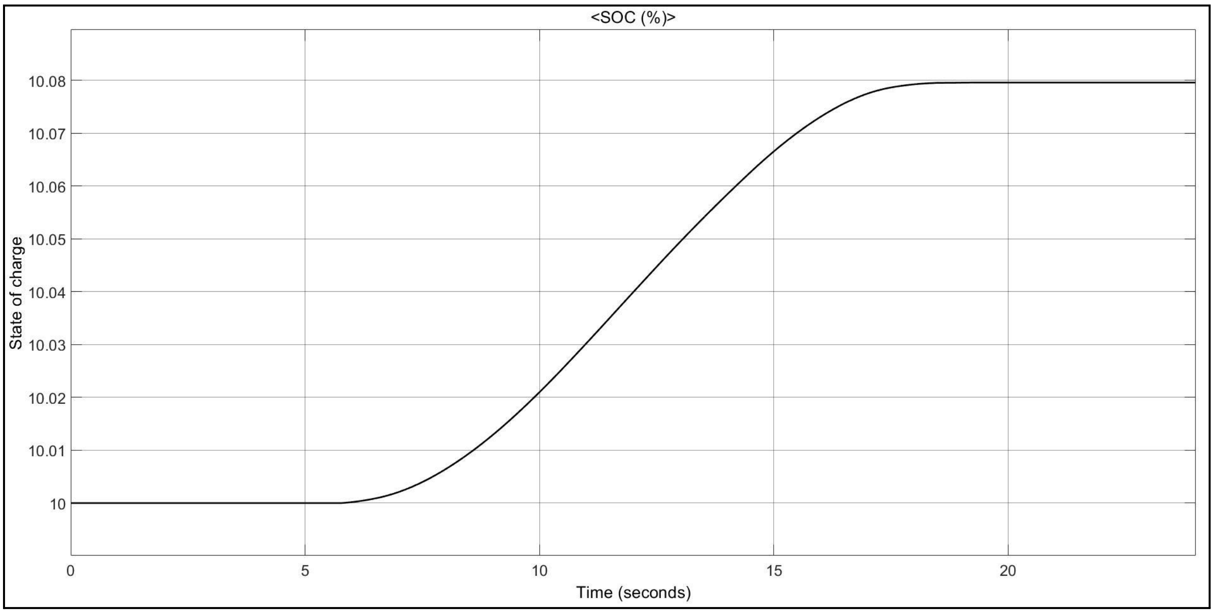
- **Simulation Results:**



(a)



(b)



(c)

Figure 32: Backup battery charging system output graph
(a)Supply voltage vs Time, (b)Supply current vs Time & SOC of battery vs Time

From the simulation result, we get the SOC of 10% at the initial level, t=0 sec. Whereas after some time at t=5.4 sec SOC starts to increase from 10% to 10.02% at time t=10 sec, which helps us to indicate if the battery is charging. It can be said from the result that the battery is going to be charged more than 40-45% in one hour considering the peak hour of a sunny day.

4.3 Identify Optimal Design Approach

Analyzing Results:

Approach 01:

Time (Second)	Supply Energy (Watt-Second/Joule)
1	258.5
2	519.7
3	776.2
4	1037
5	1293
6	1554
7	1809
8	2068
9	2323
10	2583

Table 11: Used Energy Table For Approach 01

Time (Second)	Voltage (V)	Current (Amps)	Regenerated Energy (Watt-Second/Joule)
1	41.13	0.4832	19.87
2	41.13	0.4832	39.75
3	41.13	0.4832	59.62
4	41.14	0.4832	79.50
5	41.14	0.4832	99.38
6	41.14	0.4832	119.3
7	41.14	0.4832	139.1
8	41.15	0.4832	159
9	41.15	0.4832	178.9
10	41.15	0.4832	198.8

Table 12: Regenerated Energy Table For Approach 01

After 10s total amount of energy supplied is 2583J and regained energy through regenerative braking is 198.8j. So, the efficiency of this approach is about 7.69%.

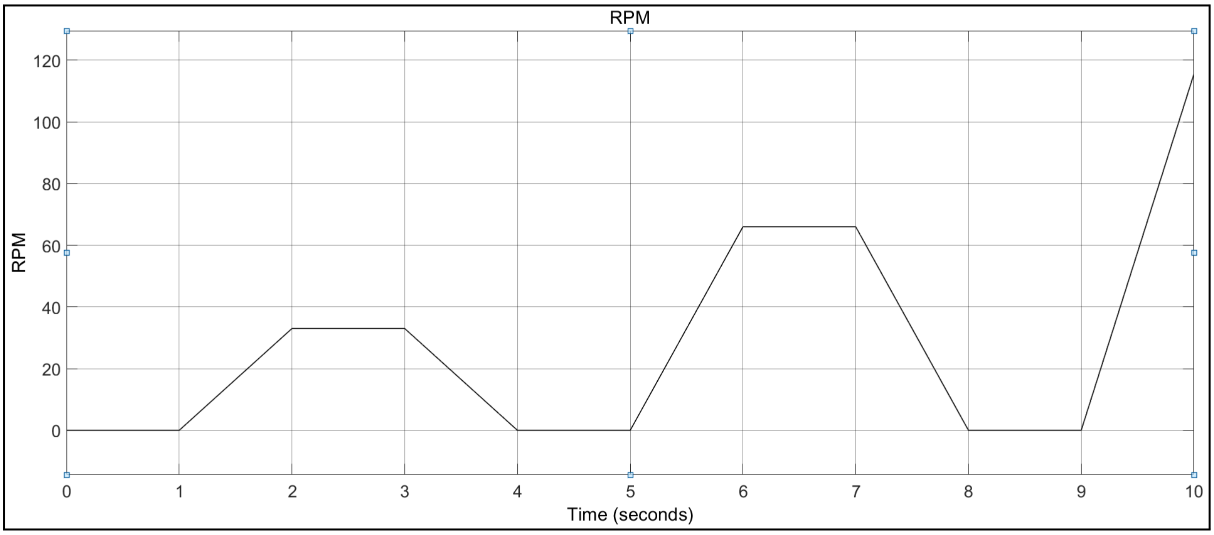


Figure 33: Rpm For Approach 01
Simulation Result Of Rpm Vs Time (S)

The average RPM shown in the simulation is about 97.4. In reality the rpm fluctuates a lot,but in this case the stable form of this rpm is for collecting the signal from a switching circuit instead of repeating sequence or any other block.

The circumference of the wheel is 2*pi*13 = 81.68inch or 2.075m for a single rotation.

As the rpm is 97.4 for a single minute. So, for an hour it will run for a distance of,

D = 2.075*60*97.4 m

= 12126.3 m

= 12.126 km

Approach 02:

Time (Second)	Supply Energy (Watt-Second/Joule)
1	288.1
2	576.3
3	863.9
4	1154
5	1442
6	1729
7	2073
8	2326
9	2580
10	2692

Table 13: Used Energy Table For Approach 02

Time (S)	Dynamo Voltage (V)	Field Current (A)	Amature Current (A)	Load Current (A) $I_L = I_A - I_F$	Energy Producing (Watt-Second/Joule)
1	5.146	1.2	1.964	0.764	3.93
2	5.147	1.2	1.964	0.764	7.86
3	5.148	1.2	1.964	0.764	11.79
4	5.156	1.2	3.272	2.072	22.47
5	5.159	1.2	3.272	2.072	33.16
6	5.161	1.2	3.272	2.072	43.86
7	5.153	1.2	1.306	0.106	44.40
8	5.154	1.2	1.306	0.106	44.95

9	5.154	1.2	1.306	0.106	45.50
10	5.152	1.2	0.653	-0.547	42.68

Table 14: Produced Energy Table For Approach 02

After 10s total amount of energy supplied is 2692J and with the help of DC Dynamo the reproduced energy amount is about 42.68j. So, the efficiency of this approach is about 1.583%.

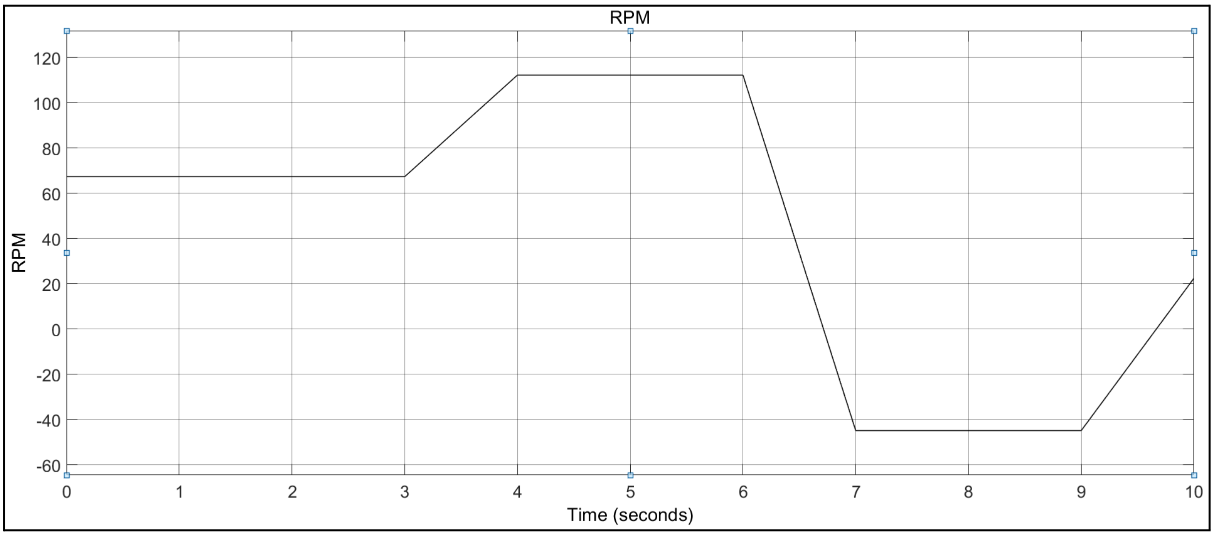


Figure 34: Rpm For Approach 02
Simulation Result Of Rpm Vs Time (S)

In the figure, the rotation speed of the motor is shown. During 0 to 3 seconds, the rotation speed remains constant at about 67.32 rpm. After 3 seconds, the rotation speed starts to increase up to 112.2rpm in one second and it remains constant again up to 6 seconds. Then the rotation speed again fluctuates.

Time (s)	RPM
1	67.32
2	67.32
3	67.32
4	112.2
5	112.2
6	112.2
7	44.88
8	44.88

9	44.88
10	22.44
	AVG RPM = 69.564

Table 15: Rpm For A Single Period Of Approach 02

The circumference of the wheel is 2*pi*13 = 81.68inch or 2.075m for a single rotation. As the rpm is 69.564 for a single minute. So, for an hour it will run for a distance of,

D = 2.075*60*69.564 m
= 8660.718 m
= 8.66 km

Approach 03:

Time (Second)	**Voltage (V)**	**Current (Amps)**	**Supplied Energy (Watt-Second/Joule)**
1	55.89	6.928	293.2
2	56.03	7.244	552.6
3	55.86	6.284	823.3
4	55.81	7.299	1073
5	55.79	7.273	1356
6	55.8	6.287	1588
7	55.75	7.234	1867
8	55.72	7.829	2118
9	55.74	6.076	2393
10	55.71	6.498	2648

Table 16: Used Energy Table For Approach 03

TIME(second)	RPM
0.105	37.8
0.21	75.6
0.315	83.76
0.42	73.68
0.525	66.3
0.63	67.56
0.735	68.82
0.84	66.84
0.945	64.32
1.05	66.6
1.155	74.16
1.26	79.92
1.365	78.58
1.47	57.24
1.575	56.7
1.68	60.48
1.785	64.68
1.89	69.72
1.995	74.76
2.1	72.6
2.205	70.08
2.31	66.84
2.415	63.06
2.52	60.48
2.625	63
2.73	65.52
2.835	71.1
2.94	77.4
3.045	78.84
3.15	73.76
3.255	68.76

3.36	63.72
3.465	58.68
3.57	62.04
3.675	69.6
3.78	73.92
3.885	70.14
3.99	66.36
4.095	67.14
4.2	68.4
4.305	67.68
4.41	65.16
4.515	64.08
4.62	71.64
4.725	79.20
4.83	77.16
4.935	72.12
5.04	69.96
5.145	72.48
5.25	25.25
	AVERAGE = 67.6738

Table 17: Rpm Vs Time Data Of One Repeating Signal Period Of Approach 03

The circumference of the wheel is 2*pi*13 = 81.68inch or 2.075m for a single rotation.
As the rpm is 67.6738 for a single minute. So, for an hour it will run for a distance of,
D = 2.075*60*67.6738 m
= 8425.3881 m
= 8.2881 km

We took 50 data point values of RPM vs Time data of one repeating signal period in order to calculate the speed and mileage of the bike for one hour of operation with an average speed considered for comparison.

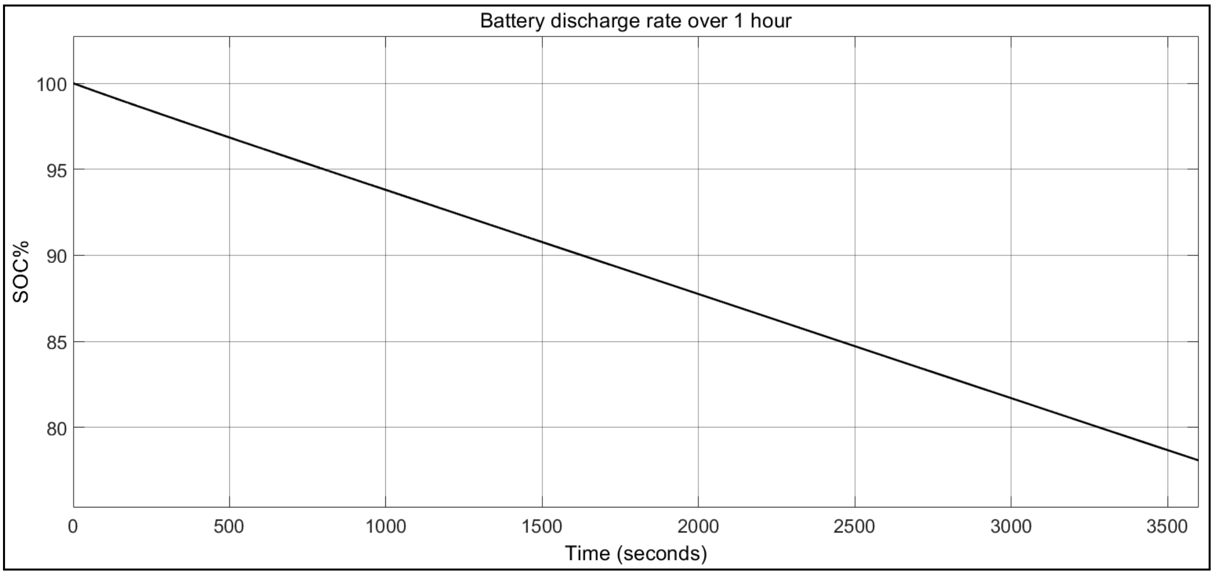


Figure 35: Soc Of Battery After 1 Hour. (78.07% Remaining).
(Soc Vs Time)

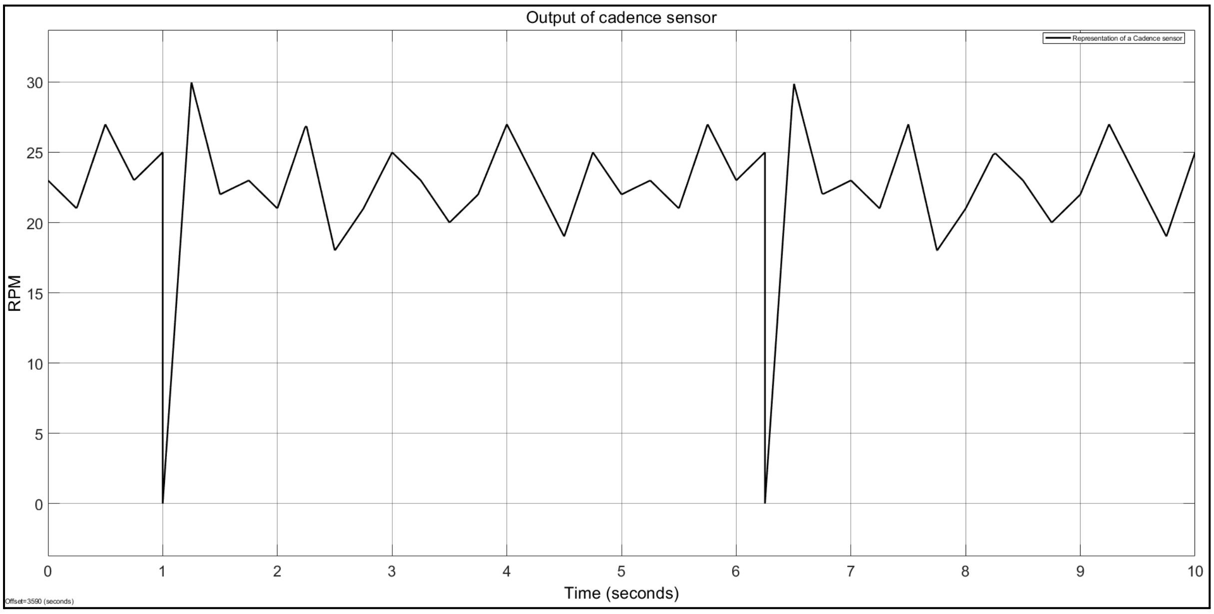


Figure 36: Output From The Representation Of The Cadence Sub-System In Simulation.
(Rpm Vs Time)

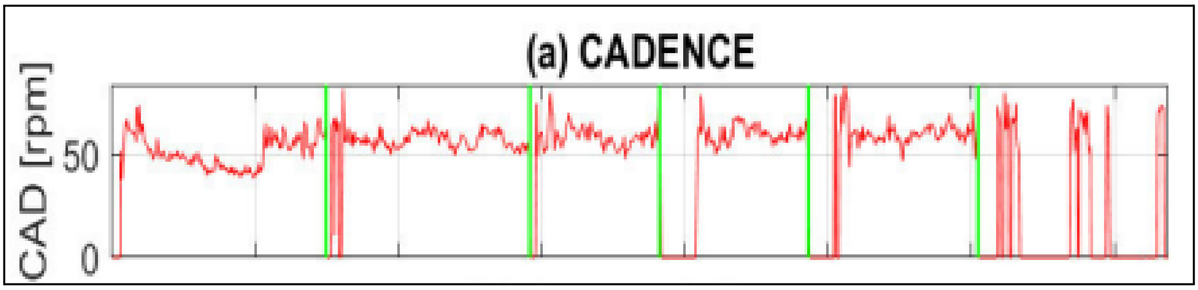


Figure 37: Cadence Signal Output Graph (Rpm Vs Time)[33]

The output of a cadence sensor is expected to have a fluctuating speed(in RPM) as the output based on a pedal rotation which is represented using a ‘Repeating Sequence’ block. Here, our reference graph of a cadence output is at figure no. 34 and the resultant output that we have got from our sub-system simulation is at figure no. **33** which has a similar ripple or fluctuating speed as an output which can be fed as an input signal to the main BLDC hub motor to increase the speed and manipulate the motor rotation based on the pedal input (Repeating Sequence).

Comparison of three designs:

	Approach-1	**Approach-2**	**Approach-3**
Energy Consumption	Supply energy is about 2583 J.	Supply energy is about 2692 J.	Supply energy is about 2648J.
Regeneration from motor	Produced energy from back emf is 198.8J	DC dynamo generates about 50.75J	No regeneration is used
Range coverage	56.325km	38.85km	37.79km
Effective energy gain of the battery	0.006711% SOC increased to a 48V 20Ah battery giving a trial for 10s.	0.0248% SOC increased only to a 6V 5Ah battery giving a trial for 10s.	There is no effective gain obtained using this design.
Cost	62,187 bdt	57,200 bdt	58,400 bdt

Table 18: Optimal Solution Comparison Of Approach 1,2 And 3

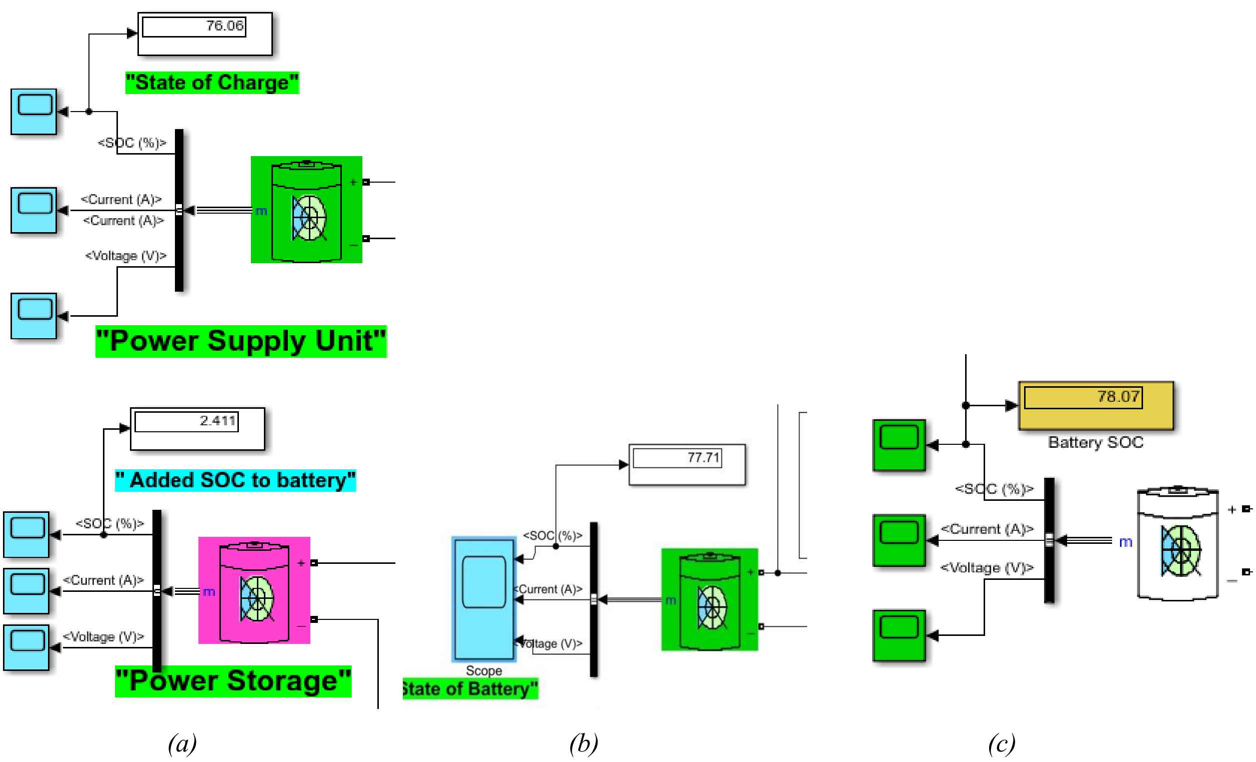


Figure 38: (a) Battery Soc And Regained Soc After 1 Hour (Approach 1)
(B) Battery Soc After 1 Hour (Approach 2)
(C) Battery Soc After 1 Hour (Approach 3)

4.4 Performance Evaluation Of Developed Solution

	SOC after 1 hour (%)	**SOC addition after to the supply battery 1 hour (%)**	**Overall SOC of the battery after 1 hour (%)**	**Distance coverage in 1 hour (km)**
Approach 1	76.06%	2.411%	78.471%	12.126 km
Approach 2	77.71%	0%	77.71%	8.66 km
Approach 3	78.07%	0%	78.07%	8.2881 km

Table 19: Comparison Of The Battery Soc & Average Distance Coverage Within A Specific Time

→Considering all the above comparisons of three designs based on their distance coverage over 1 hour run time and remaining state of charge(SOC) of the supply battery and additional energy gain represented through SOC gain, we can conclude that design approach 1 is the better performing and optimum approach among the three.

4.5 Conclusion

From the comparison table above we have found out that Design-1 is the optimal solution, which meets all the objectives of our project by keeping the system efficient. Hence, based on our stated analysis and simulated results, we have come to the conclusion that Design Approach 1 out-performs Design Approach 2 and Design 3 in almost all aspects.

Chapter 5: Completion Of Final Design And Validation [CO8]

5.1 Introduction

The implementation of the suggested plans was thoroughly compared in the preceding chapter. The systems were simulated using software to test the circuit of the prototype to get to know about the feasibility of the design. To fine-tune the system even further, many troubleshooting possibilities were offered. A hardware prototype for future testing has been created using the determined optimum solution. Among the three designs, we have come to the conclusion to build the approach of design one, which is designing a prototype using a regenerative braking system. This chapter provides a thorough summary and examination of the ideal design.

5.2 Completion Of Final Design

In figure 39, we have designed the whole prototype circuit using matlab simulink which will help us to build the prototype since we are planning to work on the regenerative braking system.

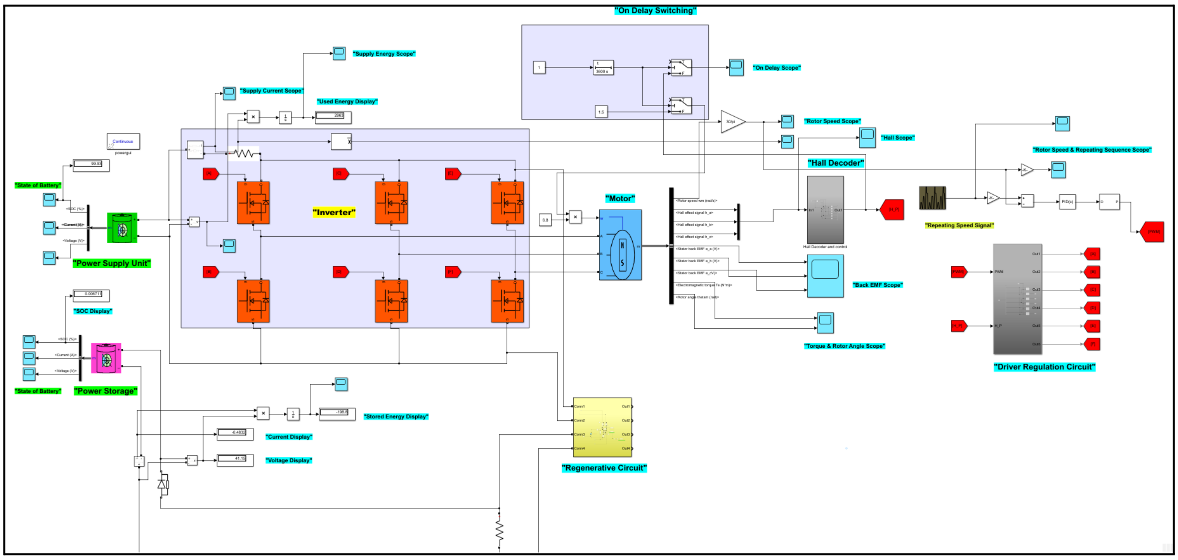


Figure 39: Simulation of the entire design process

In order to determine the sort of product consumers would like, we proceeded to get the essential information about the prototype and other designs that were already on the market. To get the advice and data we needed to construct it, we spoke with the stakeholders. In order to construct the budget and learn more about the essential components and the costs of those things, we also had to visit several stores. We made an effort to picture the small size prototype before it was put into action. To put the concept into context, we created a 3D model of the prototype, which helped with construction because it allowed us to see how the finished product would look. Figure 40 and figure 41 show the 3D design of the small size prototype in a different state.

Figure 40: 3D design of the prototype in the idle state

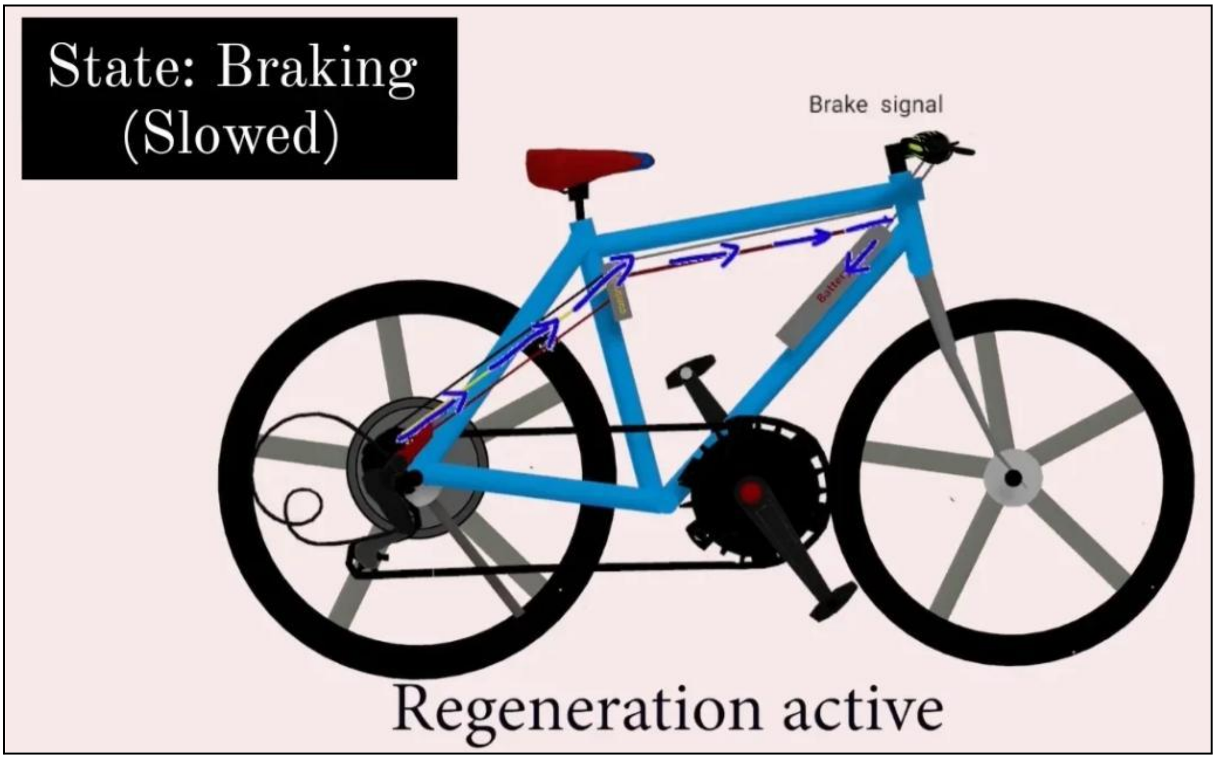


Figure 41: 3D design of the prototype in the braking state

Following the design and simulation results we started the implementation of the prototype. For the chassis of the bicycle, we had to get the body frame. So, here is our prototype body frame on which we are going to test and convert.

Figure 42: Prototype e-bike for conversion

It's crucial to choose a bike that fits properly, and is safe, sturdy, and pleasant. These are a few things to consider while picking a bike. Bikes durability plays an important role while riding a bike. Also considering framing, wheel strength, weight limit, and comfort it is preferable to use a 26-inch bike.

Figure 43: Wheel of the bike with the hub motor.

All things considered, we have chosen a 26-inch bike. As for the dimension, the tire size for the 26-inch bike is 28-62mm with 36 spokes. The actual ISO diameter of a traditional 26" wheel is 559mm

Figure 44: The main battery of the bike. Rated voltage- 48V and rated current- 10Ah.

It is the main supply source of the e-bike which has the following specifications. Rated voltage- 48V and rated current- 10Ah.

Figure 45: BLDC motor controller. Ratings: 36/48/72Volts, 17Ampare.

Figure 46: BLDC motor controller(secondary). Ratings: 36/48 Volts, 17±1 Ampere.

For the controlling of the motor, we are using a Brushless DC motor controller to control the speed of the hub motor attached with the wheel. As we know the BLDC hub motor is a three phase motor, it uses a 6 transistor(Mosfet) switching configuration as an inverter for the motor control. Here the hall sensor detects the position of the rotor at different times and sends out data to the controller for controlling the speed of the rotor with the help of the signal sent by the throttle.

Figure 47: Electric brakes of the bike

These are electric brakes that complete a circuit of the controller that enables the supply voltage of the controller to be 0 volt and allows the rotating motor to generate electricity that flows back to the battery to charge it and consequently slows down the motor in the process.

Figure 48: Throttle of the bike.

The throttle of the bike works a spring-loaded potentiometer that needs mainly 3 wires to operate. A +5 volts power port, a ground port, and a signal port which is used to increase or decrease the speed of the hub motor.

5.3 Evaluate The Solution To Meet Desired Needs:

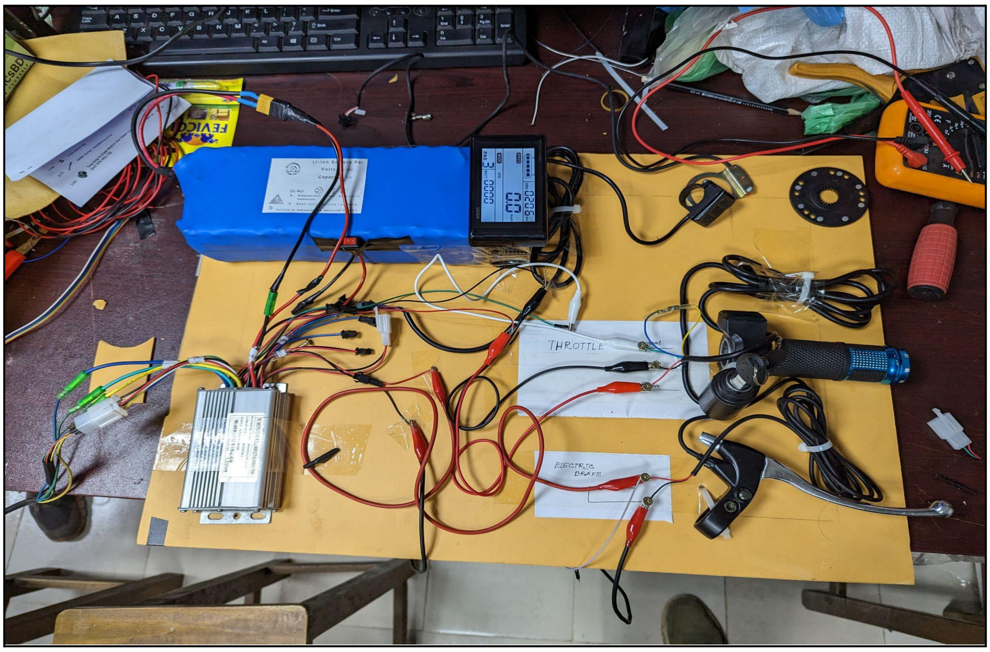


Figure 49: Prototype testing (i)

Figure 50: Prototype testing (ii)

The initial prototype trial of the e-bike has been made according to the flow diagram of the overall system. During the initial test run the top speed was noted around 28 km/hr. Moreover, the first test run gave us the least amount of data because of the current status of the testing. In a major number of portions, the regenerative braking system worked very little as it was just a freewheel instead of a proper test run without any load and without enough speed to help generate some power from the motor in the system.

Figure 51: Prototype of the e-bike

Figure 52: Battery of the e-bike

Figure 53: Multimeter and tachometer placement

Figure 54: Mounted hub motor in the wheel

5.3.1 Observation of voltage, current, power, and energy supply for free wheel rotation:

Time (s)	Speed (km/hr)	Voltage (V)	Supply Current (A)	Supply Power (W)	Supply Energy (J)
1	0	52.2	0.57	29.754	29.754
2	0	52.2	0.25	13.05	42.804
3	8.8	52.5	0.37	19.425	62.229
4	9.1	52.4	0.72	37.728	99.957
5	14.7	52.5	0.45	23.625	123.582
6	18.8	52.4	0.36	18.864	142.446
7	18.2	52.6	0.36	18.936	161.382
8	18.2	52.4	0.35	18.34	179.722
9	18.2	52.6	0.29	15.254	194.976
10	18.2	52.6	0.26	13.676	208.652
11	18.2	52.6	0.54	28.404	237.056
12	18.8	52.5	1.36	71.4	308.456
13	22.1	52.4	0.79	41.396	349.852
14	27.3	52.6	0.51	26.826	376.678
15	28.6	52.7	0.79	41.633	418.311
16	28.6	52.2	1.24	64.728	483.039
17	33.8	52.1	0.81	42.201	525.24
18	36.4	52.1	0.73	38.033	563.273
19	36.4	52.3	0.67	35.041	598.314
20	36.4	52.3	0.61	31.903	630.217
21	36.4	52.2	0.65	33.93	664.147
22	36.4	52.4	0.66	34.584	698.731
23	36.4	52.6	0.66	34.716	733.447
24	36.4	52.5	0.67	35.175	768.622
25	36.4	52.6	0.66	34.716	803.338
26	36.4	52.4	0.62	32.488	835.826
27	36.4	52.7	0.51	26.877	862.703
28	35.1	52.6	0.6	31.56	894.263
29	35.1	52.5	0.62	32.55	926.813
30	35.7	52.5	0.62	32.55	959.363
31	33.8	52.5	0.62	32.55	991.913
32	33.8	52.6	0.62	32.612	1024.525

33	33.8	52.5	0.63	33.075	1057.6
34	33.8	52.6	0.62	32.612	1090.212
35	33.8	52.4	0.63	33.012	1123.224
36	33.8	52.5	0.76	39.9	1163.124
37	33.8	52.6	0.69	36.294	1199.418
38	33.8	52.5	0.64	33.6	1233.018
39	33.8	52.6	0.64	33.664	1266.682
40	33.8	52.6	0.64	33.664	1300.346
41	33.8	52.6	0.96	50.496	1350.842
42	35.1	52.4	0.76	39.824	1390.666
43	36.4	52.5	0.72	37.8	1428.466
44	36.4	52.6	0.6	31.56	1460.026
45	36.4	52.1	0.59	30.739	1490.765
46	36.4	52.2	1.22	63.684	1554.449
47	36.4	52.5	0.74	38.85	1593.299
48	37.7	52.7	0.73	38.471	1631.77
49	37.7	52.7	0.58	30.566	1662.336
50	37.7	52.6	0.55	28.93	1691.266
51	37.7	52.4	0.64	33.536	1724.802
52	36.4	52.6	0.66	34.716	1759.518
53	36.4	52.4	0.67	35.108	1794.626
54	36.4	52.7	0.67	35.309	1829.935
55	36.4	52.5	0.67	35.175	1865.11
56	36.4	52.6	0.67	35.242	1900.352
57	36.4	52.4	0.68	35.632	1935.984
58	36.4	52.6	0.67	35.242	1971.226
59	36.4	52.6	0.67	35.242	2006.468
60	36.4	52.5	0.67	35.175	2041.643
61	36.4	52.4	0.67	35.108	2076.751
62	36.4	52.1	0.66	34.386	2111.137
63	36.4	52.6	0.66	34.716	2145.853
64	36.4	52.3	0.66	34.518	2180.371
65	36.4	52.2	0.66	34.452	2214.823
66	36.4	52.3	0.66	34.518	2249.341
67	36.4	52.5	0.5	26.25	2275.591
68	35.1	52.2	0.46	24.012	2299.603

69	33.8	52.7	0.5	26.35	2325.953
70	33.8	52.3	0.56	29.288	2355.241
71	32.5	52.3	0.58	30.334	2385.575
72	32.5	52.5	0.58	30.45	2416.025
73	32.5	52.5	0.76	39.9	2455.925
74	32.5	52.6	0.59	31.034	2486.959
75	32.5	52.4	0.45	23.58	2510.539
76	32.5	52.4	0.52	27.248	2537.787
77	32.5	52.6	0.54	28.404	2566.191
78	31.2	52.3	0.53	27.719	2593.91
79	31.2	52.5	0.59	30.975	2624.885
80	31.2	52.3	0.66	34.518	2659.403
81	31.2	52.6	0.52	27.352	2686.755
82	31.2	52.4	0.44	23.056	2709.811
83	29.9	52.4	0.64	33.536	2743.347
84	29.9	52.5	0.58	30.45	2773.797
85	29.9	52.5	1.55	81.375	2855.172
86	32.5	52.6	1.32	69.432	2924.604
87	36.9	52.7	0.67	35.309	2959.913
88	37.7	52.1	0.59	30.739	2990.652
89	37.7	52.4	0.55	28.82	3019.472
90	36.4	52.4	0.64	33.536	3053.008
91	36.4	52.1	0.6	31.26	3084.268
92	35.1	52.3	0.59	30.857	3115.125
93	35.1	52.2	0.5	26.1	3141.225
94	33.8	52.2	0.43	22.446	3163.671
95	32.5	52.1	0.55	28.655	3192.326
96	32.5	52.2	0.59	30.798	3223.124
97	32.5	52.1	0.72	37.512	3260.636
98	32.5	52.3	0.65	33.995	3294.631
99	33.8	52.1	0.64	33.344	3327.975
100	33.8	52.1	0.63	32.823	3360.798
101	33.8	52.5	0.8	42	3402.798
102	33.8	52.6	0.68	35.768	3438.566
103	33.8	52.7	0.57	30.039	3468.605
104	33.8	52.3	0.53	27.719	3496.324

105	33.8	52.1	0.47	24.487	3520.811
106	33.8	52.4	0.58	30.392	3551.203
107	33.8	52.5	0.51	26.775	3577.978
108	32.5	52.3	0.65	33.995	3611.973
109	32.5	52.7	0.67	35.309	3647.282
110	33.8	52.6	0.68	35.768	3683.05
111	33.8	52.7	0.65	34.255	3717.305
112	33.8	52.7	0.64	33.728	3751.033
113	33.8	52.5	0.58	30.45	3781.483
114	33.8	52.7	0.48	25.296	3806.779
115	33.8	52.3	0.63	32.949	3839.728
116	33.8	52.6	0.58	30.508	3870.236
117	32.5	52.7	0.6	31.62	3901.856
118	32.5	52.1	0.67	34.907	3936.763
119	32.5	52.6	0.64	33.664	3970.427
120	32.5	52.5	0.63	33.075	4003.502

Table 20 : Supply current, voltage, power and energy for free wheel rotation

The amount of supplied energy is around 4003.502joules with the conventional braking system and for that amount of supply we had to take around 2 minutes of time frame. Between this test, the supplied voltage was always constant and it remained between 52.1 to 52.7 volts. The current consumption was according to the speed of the two wheeler. Theoretically speed and current consumption are proportional to each other. While the throttle is positioned to speed up the two wheeler, the current rises to a certain amount. 1.55 amps was the highest current consumption at 85th second.

5.3.2 Observation of voltage, current, power and energy supply for free wheel rotation using regenerative braking:

Time (s)	Speed (km/hr)	Voltage (V)	Supply Current (A)	Supply Power (W)	Supply Energy (J)
1	11.2	52.2	0.22	11.484	11.484
2	11.7	52.3	0.29	15.167	26.651
3	13	52.4	0.28	14.672	41.323
4	13	52.1	1.44	75.024	116.347
5	14.3	52.6	0.82	43.132	159.479
6	19.5	52.1	0.45	23.445	182.924
7	22.1	52.4	0.37	19.388	202.312
8	22.1	52.3	0.35	18.305	220.617
9	22.1	52.6	0.39	20.514	241.131
10	22.1	52.3	0.4	20.92	262.051
11	22.1	52.1	0.39	20.319	282.37
12	22.1	52.6	0.4	21.04	303.41
13	22.1	52.5	0.38	19.95	323.36
14	22.1	52.5	0.38	19.95	343.31
15	22.1	52.6	0.44	23.144	366.454
16	22.1	52.1	0.78	40.638	407.092
17	26	52.3	0.56	29.288	436.38
18	26	52.4	0.71	37.204	473.584
19	27.3	52.3	0.57	29.811	503.395
20	28.6	52.1	0.63	32.823	536.218
21	28.6	52.1	0.84	43.764	579.982
22	29.9	52.2	0.71	37.062	617.044
23	31.2	52.1	0.68	35.428	652.472
24	32.5	52.1	0.73	38.033	690.505
25	32.5	52.2	0.66	34.452	724.957
26	33.8	52.5	0.67	35.175	760.132
27	33.8	52.6	0.65	34.19	794.322
28	33.8	52.6	0.7	36.82	831.142
29	33.8	52.6	0.67	35.242	866.384
30	33.8	52.4	0.74	38.776	905.16
31	33.8	52.3	0.77	40.271	945.431
32	35.1	52.5	0.7	36.75	982.181

33	35.1	52.6	0.69	36.294	1018.475
34	35.1	52.5	0.69	36.225	1054.7
35	35.1	52.1	0.68	35.428	1090.128
36	35.1	52.2	0.69	36.018	1126.146
37	35.1	52.1	0.68	35.428	1161.574
38	35.1	52.6	0.68	35.768	1197.342
39	35.1	52.1	0.68	35.428	1232.77
40	35.1	52.1	0.69	35.949	1268.719
41	35.1	52.2	0.69	36.018	1304.737
42	35.1	52.1	0.69	35.949	1340.686
43	35.1	52.1	0.69	35.949	1376.635
44	35.1	52.1	0.69	35.949	1412.584
45	35.1	52.6	0.66	34.716	1447.3
46	35.1	52.5	0.71	37.275	1484.575
47	36.4	52.3	0.7	36.61	1521.185
48	36.4	52.4	0.65	34.06	1555.245
49	36.4	52.3	0.67	35.041	1590.286
50	36.4	52.5	0.68	35.7	1625.986
51	36.4	52.6	0.69	36.294	1662.28
52	36.4	52.6	0.68	35.768	1698.048
53	36.4	52.3	0.68	35.564	1733.612
54	36.4	52.3	0.69	36.087	1769.699
55	36.4	52.1	0.68	35.428	1805.127
56	36.4	52.2	0.68	35.496	1840.623
57	36.4	52.2	0.68	35.496	1876.119
58	36.4	52.4	0.66	34.584	1910.703
59	36.4	52.6	0.66	34.716	1945.419
60	36.4	52.1	0.15	7.815	1953.234
61	26.8	52.2	0.11	5.742	1958.976
62	16.9	52.2	0.07	3.654	1962.63
63	10.4	52.3	0.03	1.569	1964.199
64	9.1	52.4	0.03	1.572	1965.771
65	6.5	52.5	0.03	1.575	1967.346
66	0	52.5	0.03	1.575	1968.921
67	0	52.5	0.03	1.575	1970.496
68	0	52.5	0.03	1.575	1972.071

69	0	52.5	0.03	1.575	1973.646
70	0	52.5	0.03	1.575	1975.221
71	0	52.5	0.03	1.575	1976.796
72	0	52.5	0.03	1.575	1978.371
73	0	52.7	1.12	59.024	2037.395
74	11.7	52.1	0.51	26.571	2063.966
75	30	52.1	0.34	17.714	2081.68
76	14.3	52.4	0.34	17.816	2099.496
77	15.6	52.3	0.35	18.305	2117.801
78	16.9	52.6	1.49	78.374	2196.175
79	20.8	52.1	0.71	36.991	2233.166
80	37.3	52.1	0.52	27.092	2260.258
81	27.3	52.3	0.44	23.012	2283.27
82	27.3	52.1	0.44	22.924	2306.194
83	27.3	52.1	0.46	23.966	2330.16
84	27.3	52.7	0.72	37.944	2368.104
85	27.3	52.7	0.56	29.512	2397.616
86	27.3	52.5	0.61	32.025	2429.641
87	28.6	52.1	0.63	32.823	2462.464
88	29.9	52.3	0.8	41.84	2504.304
89	31.2	52.6	1.01	53.126	2557.43
90	32.5	52.6	0.76	39.976	2597.406
91	35.1	52.5	0.68	35.7	2633.106
92	35.1	52.2	0.67	34.974	2668.08
93	35.1	52.1	0.67	34.907	2702.987
94	35.1	52.5	0.67	35.175	2738.162
95	35.1	52.5	0.67	35.175	2773.337
96	35.1	52.6	0.59	31.034	2804.371
97	35.1	52.3	0.62	32.426	2836.797
98	35.1	52.3	0.63	32.949	2869.746
99	35.1	52.2	0.63	32.886	2902.632
100	35.1	52.1	0.64	33.344	2935.976
101	35.1	52.5	0.56	29.4	2965.376
102	35.1	52.4	0.59	30.916	2996.292
103	33.8	52.7	0.6	31.62	3027.912
104	33.8	52.3	0.57	29.811	3057.723

105	33.8	52.7	0.57	30.039	3087.762
106	33.8	52.6	0.54	28.404	3116.166
107	32.5	52.7	0.5	26.35	3142.516
108	32.5	52.1	0.52	27.092	3169.608
109	32.5	52.1	0.56	29.176	3198.784
110	31.2	52.5	0.57	29.925	3228.709
111	31.2	52.1	0.57	29.697	3258.406
112	31.2	52.7	0.57	30.039	3288.445
113	31.2	52.3	0.57	29.811	3318.256
114	31.2	52.3	0.7	36.61	3354.866
115	31.2	52.4	0.62	32.488	3387.354
116	31.2	52.5	0.6	31.5	3418.854
117	31.2	52.5	0.6	31.5	3450.354
118	31.2	52.5	0.65	34.125	3484.479
119	31.2	52.1	0.63	32.823	3517.302
120	32.5	52.6	0.59	31.034	3548.336

Table 21: Current, voltage, power and energy for free wheel rotation using regenerative braking.

Here we measured the supply voltage, current, power and energy from the freewheel experiment of the motor controller. We set up the controller with the motor controller, throttle and electric brakes in a trainer board configuration with the motor wheel free to move on a wheel stand. We tested The wheel speed with a 2-minute time frame for each second, taking the data of instantaneous speed, current consumption, power and energy drawn from the battery by the controller in different time intervals. While using regenerative braking the amount of energy consumed to operate the two wheeler is about 3548.336 joules. In between 62s to 72s the regenerative braking was activated and the supply current was 0.03amps during this period.

5.3.3 A brief comparison between energy consumed by the motor while not using regenerative braking and using regenerative braking:

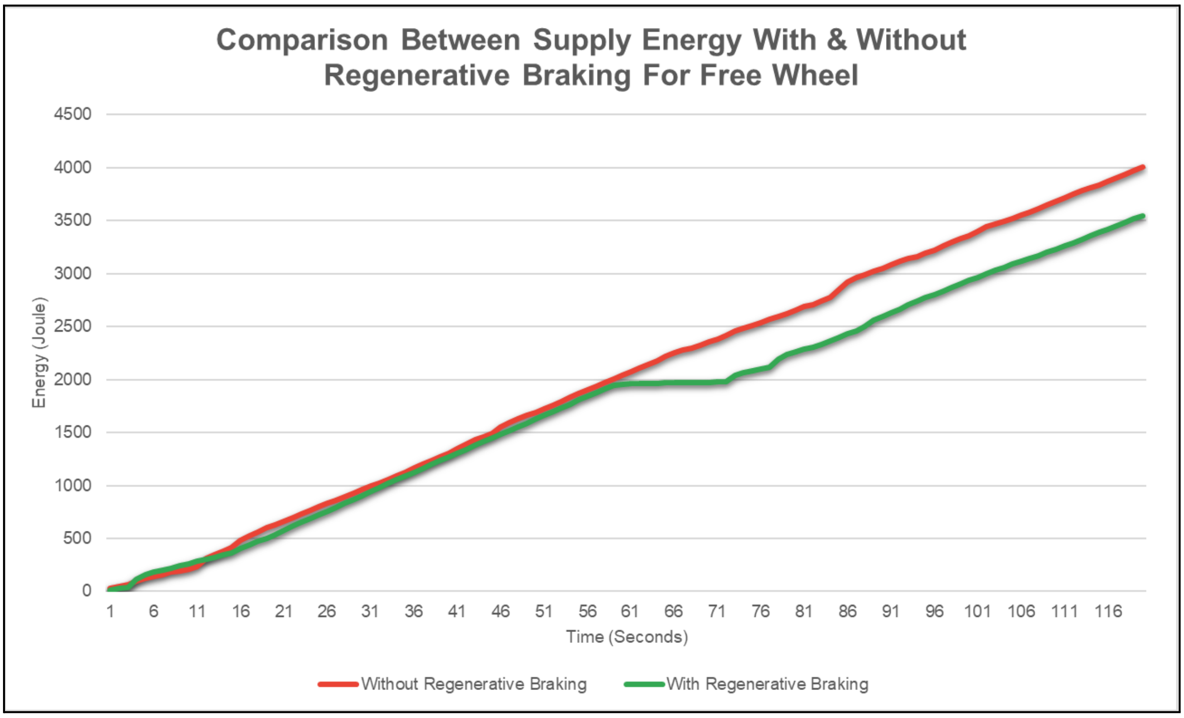


Figure 55: Comparison between with and without regenerative braking of supply energy

We determined the total energy consumption of the motor through the controller by measuring the current values in different time frames(for the first 120 seconds). It is visible that the total energy consumption of the motor is 4003.502 J or 4.004 kJ when we are not using regenerative braking. On the other hand, we get a total energy consumption of 3548.336 J or 3.548 kJ when we use the electric or regenerative brake to bring the motor to a stop. We can see that by using regenerative braking we could save 455.166 Joules of energy consumption over the course of 120 seconds during the free wheel test. Moreover, It can be observed that by using regenerative braking we can ensure less energy consumption by the controller thus preserving the supply energy from the battery especially in longer operation or travel time.

5.3.4 Observation of voltage, current, power and energy supply using friction brake with load(72 kg):

Time (s)	Speed (km/hr)	Voltage (V)	Supply Current (A)	Supply Power (W)	Supply Energy (J)
0	0	0	0	0	0
1	3.9	50.9	7.59	386.331	386.331
2	7.8	50.5	0.38	19.19	405.521
3	9.1	46.3	2.38	110.194	515.715
4	9.1	47.8	4.47	213.666	729.381
5	7.8	47.4	2.55	120.87	850.251
6	6.5	50.8	0.48	24.384	874.635
7	6.5	47.6	15.11	719.236	1593.871
8	9.1	50.8	0.04	2.032	1595.903
9	10.4	47.6	8.67	412.692	2008.595
10	10.4	48.8	0.03	1.464	2010.059
11	10.4	50.8	7.47	379.476	2389.535
12	11.7	50.8	0.04	2.032	2391.567
13	11.7	51.1	9.47	483.917	2875.484
14	13	50.5	2.88	145.44	3020.924
15	13	50.2	0.45	22.59	3043.514
16	11.7	46.7	0.03	1.401	3044.915
17	10.4	49.9	0.26	12.974	3057.889
18	6.5	51	0.59	30.09	3087.979
19	6.5	48.8	2.15	104.92	3192.899
20	6.5	48.6	3.56	173.016	3365.915
21	6.5	50.9	6.72	342.048	3707.963
22	6.5	48.7	2.71	131.977	3839.94
23	6.5	50.3	0.4	20.12	3860.06
24	5.2	50.7	0.03	1.521	3861.581
25	3.9	49.7	2.39	118.783	3980.364
26	3.9	50.8	14.78	750.824	4731.188
27	3.9	50.2	0.03	1.506	4732.694
28	3.9	51.1	2.4	122.64	4855.334
29	5.2	50.6	0.87	44.022	4899.356
30	5.2	51.3	0.03	1.539	4900.895
31	6.5	50.8	0.03	1.524	4902.419

32	7.8	50.8	0.04	2.032	4904.451
33	7.6	50.5	0.03	1.515	4905.966
34	3.78	50.4	4.78	240.912	5146.878
35	6.5	48.2	6.1	294.02	5440.898
36	11.7	42.9	2.72	116.688	5557.586
37	13	50.8	6.2	314.96	5872.546
38	13	50.3	0.17	8.551	5881.097
39	10.4	49.9	2.17	108.283	5989.38
40	10.4	51.6	0.03	1.548	5990.928
41	10.4	48.7	0.04	1.948	5992.876
42	9.1	50.4	0.03	1.512	5994.388
43	9.1	50.1	1.39	69.639	6064.027
44	9.1	47.4	0.18	8.532	6072.559
45	9.1	51.8	0.03	1.554	6074.113
46	9.1	50.7	2.18	110.526	6184.639
47	9.1	51.3	0.12	6.156	6190.795
48	2.1	47.6	0.03	1.428	6192.223
49	5.5	47.4	0.03	1.422	6193.645
50	7	51.2	0.38	19.456	6213.101
51	5.2	50.3	0.03	1.509	6214.61
52	3.9	50.1	3.62	181.362	6395.972
53	3.9	50.7	0.03	1.521	6397.493
54	3.9	51.1	3.27	167.097	6564.59
55	6.5	51.6	5.83	300.828	6865.418
56	10.4	47.6	0.07	3.332	6868.75
57	10.4	49.3	0.03	1.479	6870.229
58	10.4	50.4	2.48	124.992	6995.221
59	10.4	50.6	0.03	1.518	6996.739
60	11.7	49.9	0.03	1.497	6998.236

Table 22: Supply current, voltage, power and energy using friction brake with load

Here, we have collected data of supply voltage and current simultaneously for different speed and braking conditions with a 72 Kg load. We have slowed down the bike after every 15-20 seconds using friction braking and noted down the supply current drop at that time interval. Using the current and voltage values at every second we calculated the supply power and supplied energy to the motor at each second and created the above data table.

5.3.5 Observation of voltage, current, power and energy supply using regenerative braking with 72 kg of load:

Time (s)	Speed (km/hr)	Voltage (V)	Supply Current (A)	Supply Power (W)	Supply Energy (J)
0	0	0	0	0	0
1	5.2	47.7	6.12	291.924	291.924
2	5.2	46.5	6.39	297.135	589.059
3	3.9	46.8	0.03	1.404	590.463
4	3.9	50.3	5.24	263.572	854.035
5	3.9	50.2	1.4	70.28	924.315
6	3.9	50.6	8.96	453.376	1377.691
7	5.2	50.1	3	150.3	1527.991
8	5.2	46.5	0.06	2.79	1530.781
9	7.8	50.1	3.45	172.845	1703.626
10	9.1	50.4	0.03	1.512	1705.138
11	10.4	50.5	0.03	1.515	1706.653
12	10.4	50.2	0.03	1.506	1708.159
13	10.4	50.1	0.03	1.503	1709.662
14	10	48.3	0.7	33.81	1743.472
15	10.4	47.6	0.03	1.428	1744.9
16	10.4	50.5	6.35	320.675	2065.575
17	10.4	50.7	7.25	367.575	2433.15
18	10.4	50.8	3.45	175.26	2608.41
19	10.4	50.5	6.72	339.36	2947.77
20	13	50.2	9.89	496.478	3444.248
21	14.3	50.7	-0.1	-5.07	3439.178
22	14.3	50.1	-0.78	-39.078	3400.1
23	14.3	49.4	-0.1	-4.94	3395.16
24	11.7	46.9	0.03	1.407	3396.567
25	10.4	50.8	0.04	2.032	3398.599
26	7.8	50.3	0.03	1.509	3400.108
27	5.2	50.7	0.03	1.521	3401.629
28	5.2	50.2	0.03	1.506	3403.135

29	5.2	50.1	0.03	1.503	3404.638
30	3.9	50.4	7.18	361.872	3766.51
31	3.9	47.9	6.7	320.93	4087.44
32	3.9	48.4	0.03	1.452	4088.892
33	5.2	47.7	0.03	1.431	4090.323
34	5.2	49.6	0.89	44.144	4134.467
35	5.2	50.9	0.03	1.527	4135.994
36	7.8	50.7	0.02	1.014	4137.008
37	9.1	50.2	0.03	1.506	4138.514
38	10.4	50.6	0.04	2.024	4140.538
39	10.4	50.7	0.03	1.521	4142.059
40	10.4	50.1	0.03	1.503	4143.562
41	10.4	46.7	0.03	1.401	4144.963
42	10.4	46.7	12.01	560.867	4705.83
43	10.4	48.9	0.04	1.956	4707.786
44	13	50.7	0.1	5.07	4712.856
45	13	50.4	0.04	2.016	4714.872
46	13	50.1	0.04	2.004	4716.876
47	10.4	50.6	0.03	1.518	4718.394
48	10.4	50.7	1	50.7	4769.094
49	13	50.3	1	50.3	4819.394
50	14.3	50.8	1	50.8	4870.194
51	18.2	50.6	-2.1	-106.26	4763.934
52	18.2	50.4	-1.04	-52.416	4711.518
53	14.3	49.9	0.1	4.99	4716.508
54	10.4	50.7	0.03	1.521	4718.029
55	9.1	50.3	0.03	1.509	4719.538
56	6.5	50.1	0.04	2.004	4721.542
57	6.5	50.1	1	50.1	4771.642
58	7.8	50.3	0.04	2.012	4773.654
59	7.8	45.7	0.03	1.371	4775.025
60	6.5	50.1	0.04	2.004	4777.029
61	6.5	50.6	1	50.6	4827.629

62	5.2	50.1	11.3	566.13	5393.759
63	5.2	50.5	0.04	2.02	5395.779
64	5.2	50.3	7.96	400.388	5796.167
65	5.2	50.4	5.68	286.272	6082.439
66	6.5	48.7	0.04	1.948	6084.387
67	6.5	50.3	0.89	44.767	6129.154
68	6.5	46.6	0.09	4.194	6133.348
69	6.5	47.9	0.03	1.437	6134.785
70	6.5	46.7	0.03	1.401	6136.186
71	6.5	50.3	1	50.3	6186.486
72	9.1	50.9	1	50.9	6237.386
73	14.9	50.7	1	50.7	6288.086
74	18.2	50.3	0.19	9.557	6297.643
75	19.5	45.6	-1.17	-53.352	6244.291
76	13	46.7	0.04	1.868	6246.159
77	11.7	48.6	0.04	1.944	6248.103
78	11.7	50.4	1	50.4	6298.503
79	11.7	50.7	1	50.7	6349.203
80	14.3	50.1	-0.66	-33.066	6316.137
81	14.3	50.3	0.04	2.012	6318.149
82	11.7	50.6	1	50.6	6368.749
83	11.7	50.2	1	50.2	6418.949
84	13	50.7	-0.04	-2.028	6416.921
85	13	50.1	0.04	2.004	6418.925
86	11.7	50.5	0.04	2.02	6420.945
87	9.1	50.5	0.04	2.02	6422.965
88	6.5	48.8	18	878.4	7301.365
89	6.5	50.7	0.11	5.577	7306.942
90	5.2	50.1	1	50.1	7357.042
91	5.2	50.6	1	50.6	7407.642
92	6.5	50.2	0.04	2.008	7409.65
93	7.8	50.3	0.03	1.509	7411.159
94	7.8	50.4	0.04	2.016	7413.175

95	7.8	50.3	0.03	1.509	7414.684
96	7.8	50.1	0.04	2.004	7416.688
97	7.8	50.7	0.87	44.109	7460.797
98	7.8	50.9	0.04	2.036	7462.833
99	7.8	50.8	5.39	273.812	7736.645
100	10.4	47.1	0.7	32.97	7769.615
101	10.4	47.3	0.04	1.892	7771.507
102	10.4	50.2	0.04	2.008	7773.515
103	10.4	50.1	1	50.1	7823.615
104	10.4	50.7	0.03	1.521	7825.136
105	11.7	50.3	0.04	2.012	7827.148
106	11.7	50.3	0.03	1.509	7828.657
107	11.7	49.7	0.04	1.988	7830.645
108	11.7	50.2	0.04	2.008	7832.653
109	11.7	50.4	0.04	2.016	7834.669
110	10.4	50.7	10.03	508.521	8343.19
111	11.7	50.3	8.21	412.963	8756.153
112	13	50.2	0.08	4.016	8760.169
113	13	48.8	15.93	777.384	9537.553
114	13	50.3	0.04	2.012	9539.565
115	11.7	50.5	0.04	2.02	9541.585
116	10.4	50	0.07	3.5	9545.085
117	9.1	50.3	0.04	2.012	9547.097
118	7.8	47.8	0.03	1.434	9548.531
119	7.8	50.3	0.04	2.012	9550.543
120	6.5	49.9	0.03	1.497	9552.04

Table 23: Supply current, voltage, power and energy using regenerative braking with 72 kg of load

Here, we have collected the same data of supply voltage and current simultaneously for different speed and braking conditions as well. We have slowed down the bike after every 15-20 seconds using regenerative braking and noted down the supply current drop at that time interval. Moreover, using the current and voltage values at every second time frame, we calculated the supply power and supplied energy to the motor at each second and created the above data table for.

5.3.6 A brief comparison between energy consumed by the motor with and without using regenerative braking for a 72 Kg load:

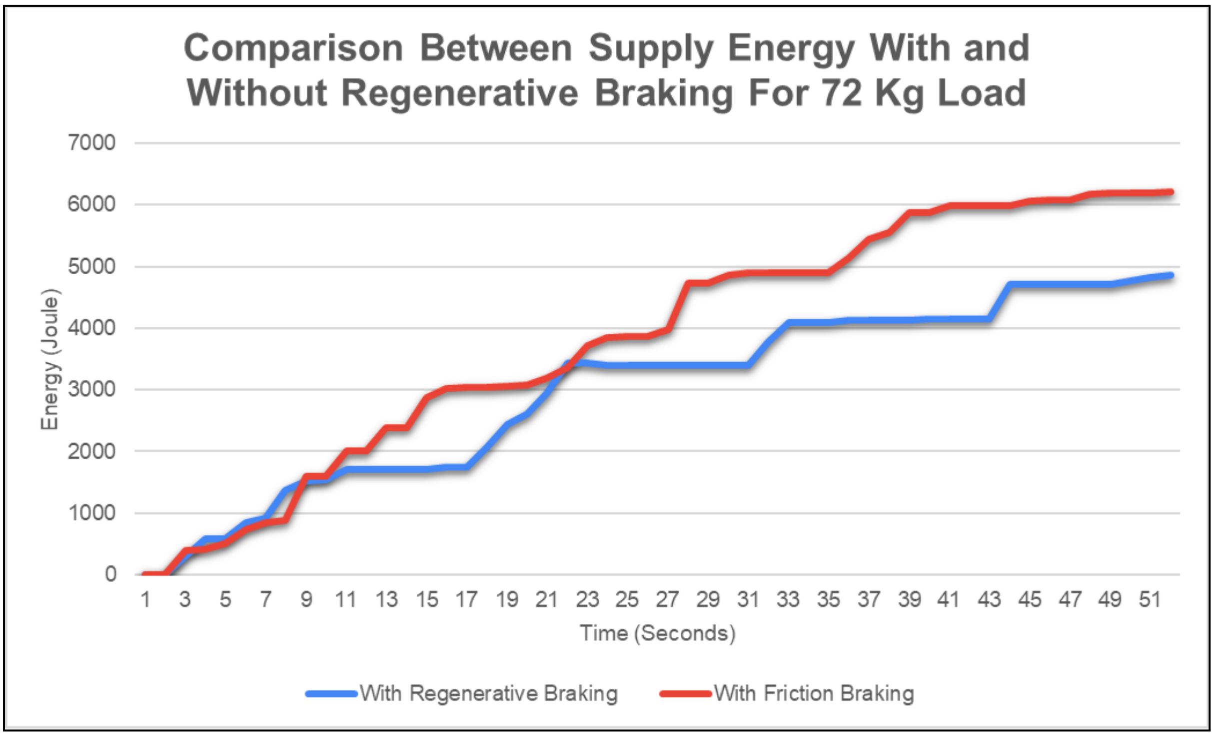


Figure 56: Comparison between with and without regenerative braking of supply energy with 72 Kg load.

The above graph demonstrates the difference between energy consumptions of the BLDC motor through the controller while using the regenerative braking and using the regular friction braking. We can see both of the graphs started at a similar point in time(at 2nd second) and consumed almost the same amount of energy when the throttle is pressed and the bike starts to accelerate. After that we can see the difference from the 9th to 7th second mark. at the 9th second both of the braking systems are applied. When only the friction brake is applied it brings the wheel speed down using only friction of the wheel disc but does not lower the current consumption of the motor. On the other hand, when the regenerative brake is pressed, it cuts the supply towards the motor from the controller and allows the motor to generate electricity from its moment of inertia and slow itself down by creating a negative instant torque as a consequence. That generated electricity is fed back to the battery during the braking period as well which prevents some energy loss during the braking instances. This small energy savings will add up to lessen the overall energy consumption of the battery which will increase the mileage/covered distance of e-bike in the long run. We can see the same braking effect from the 23rd second and onwards. As a result we can see the trend of decreased energy consumption of the motor while using the regenerative braking system compared to while using the friction disc braking on the e-bike as it covers more and more distance. So, we can clarify that the performance of the e-bike is better with the use of regenerative braking instead of traditional friction braking.

5.3.7 Observation of voltage, current, power and energy supply using regenerative braking with 58 kg of load:

Time (s)	Speed (km/hr)	Voltage (V)	Supply Current (A)	Supply Power (W)	Supply Energy (J)
0	0	47.6	0	0	0
1	0	46.5	5.39	250.635	250.635
2	6.5	50.4	8.36	421.344	671.979
3	7.8	50.7	6.93	351.351	1023.33
4	7.8	50.4	0.84	42.336	1065.666
5	9.1	50.1	7.48	374.748	1440.414
6	11	49.7	9.1	452.27	1892.684
7	11	50.5	-0.1	-5.05	1887.634
8	13	50.9	7.1	361.39	2249.024
9	13	50.7	0.03	1.521	2250.545
10	13	50.4	0.1	5.04	2255.585
11	13	45.5	0.03	1.365	2256.95
12	9.1	46.7	0.04	1.868	2258.818
13	9.1	50.2	0.03	1.506	2260.324
14	0	48.7	0.03	1.461	2261.785
15	2.6	50.7	0.03	1.521	2263.306
16	5.2	50.1	0.66	33.066	2296.372
17	3.9	50.6	1.7	86.02	2382.392
18	9.1	50.2	6.28	315.256	2697.648
19	11.7	50.4	1.47	74.088	2771.736
20	13	47.6	0.04	1.904	2773.64
21	14.3	46.7	0.03	1.401	2775.041
22	14.3	50.5	2.74	138.37	2913.411
23	14.3	50.2	0.03	1.506	2914.917
24	14.3	50	0.03	1.5	2916.417
25	13	50.3	0.21	10.563	2926.98
26	13	50	0.03	1.5	2928.48
27	13	50.6	0.03	1.518	2929.998
28	13	48.3	2.15	103.845	3033.843
29	13	50.2	2.5	125.5	3159.343
30	13	50.6	0.03	1.518	3160.861
31	11.7	50.1	0.03	1.503	3162.364

32	10.4	50.4	0.03	1.512	3163.876
33	10.4	50.5	1.67	84.335	3248.211
34	10.4	47.6	0.03	1.428	3249.639
35	9.1	48.3	0.09	4.347	3253.986
36	6.5	50.4	3.21	161.784	3415.77
37	5.2	49.4	5.51	272.194	3687.964
38	5.2	50.3	0.02	1.006	3688.97
39	5.2	50.7	8.54	432.978	4121.948
40	5.2	49.5	5.62	278.19	4400.138
41	5.2	49.2	0.63	30.996	4431.134
42	6.5	46.7	3.1	144.77	4575.904
43	7.8	50.3	0.76	38.228	4614.132
44	9.1	50.8	-0.15	-7.62	4606.512
45	10.4	45.5	0.11	5.005	4611.517
46	10.4	48.3	3.17	153.111	4764.628
47	10.4	50.5	0.04	2.02	4766.648
48	9.4	50.3	0.03	1.509	4768.157
49	9.1	50.1	0.04	2.004	4770.161
50	7.8	49.6	0.04	1.984	4772.145

Table 24: Supply current, voltage, power and energy using regenerative braking with 58 kg of load

Here, we have also collected the same data of supply voltage and current simultaneously for different speed and braking conditions for a 58 Kg load and observe the difference. We followed the same procedure when measuring with a different load. Here we used only regenerative braking after every 15-20 seconds to bring the wheel speed down. After that we collected the real time voltage and current value at each second and calculated the total supply power and energy for the motor, then compared these data with the calculated data acquired from using the 72 Kg load as well.

5.3.8 A brief comparison between supply energy for two different loads of 72 Kg & 58 Kg with regenerative braking in the working:

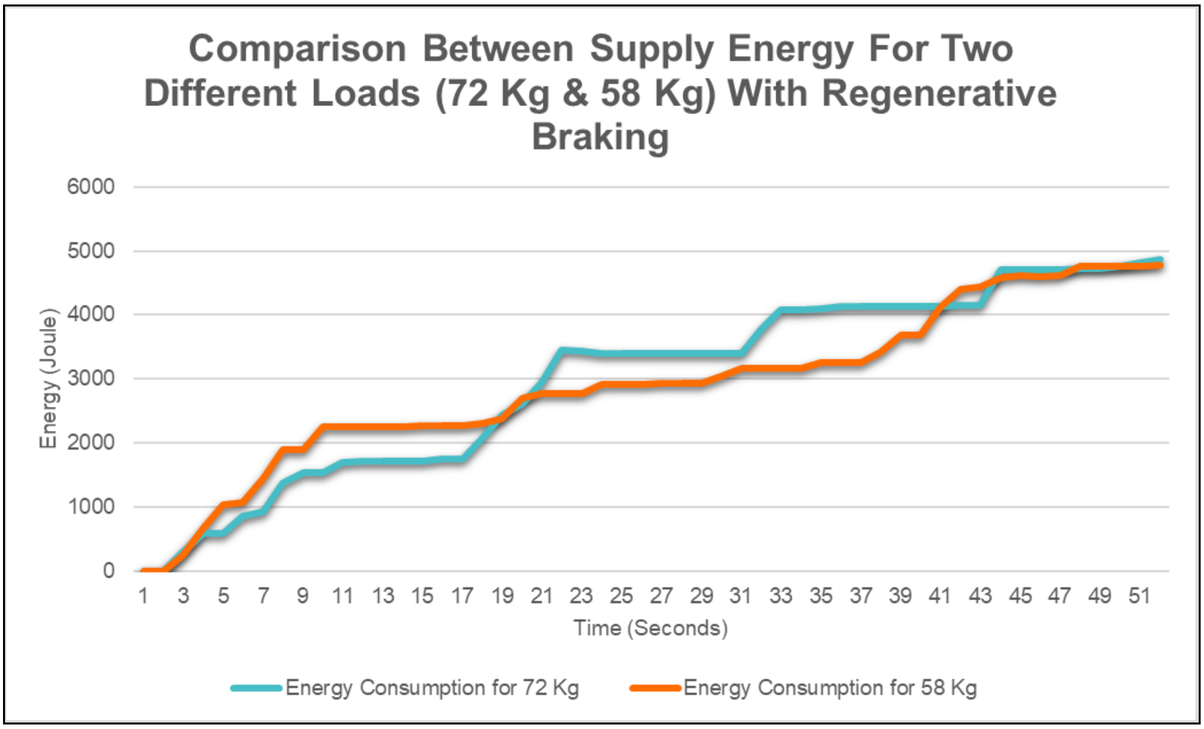


Figure 57: Comparison between supply energy for two different loads (72 Kg & 58 Kg).

The above graph shows a competitive difference between the energy consumption of the BLDC motor with different loads(72 Kg & 58 Kg) on the e-bike using the regenerative braking for both loads. Here we have the previous data of the gradual energy consumption with a 72 Kg load which shows a steady increase. As the energy consumption very much depends on the rider and his/her throttle action and braking timing, we tried to keep them as similar as possible. Energy consumption for both loads started in a similar manner. At first from the 4th to the 19th-second energy consumption for the 58 Kg load is higher. After that from the 19th to the 41st second the energy consumption for a 72 Kg load is higher which shows that the energy consumption of a motor with a 72 Kg load is higher than that with 58 Kg load for a longer time in a fixed time frame. This trend will be continued as the e-bike travels more distance.

5.3.9 Real time current and voltage values vs time graphs for both 72 Kg & 58 Kg loads using regenerative braking:

(Current and Voltage graph for 72 Kg load)

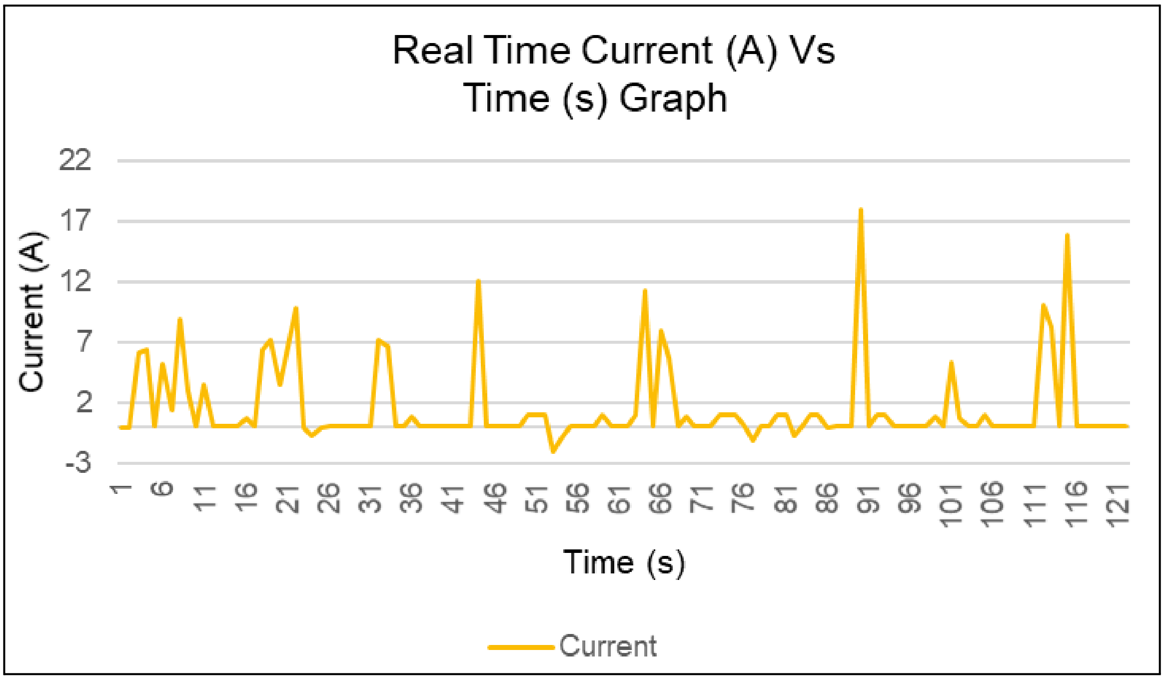


Figure 58: Supply current(A) to the motor vs time(s).

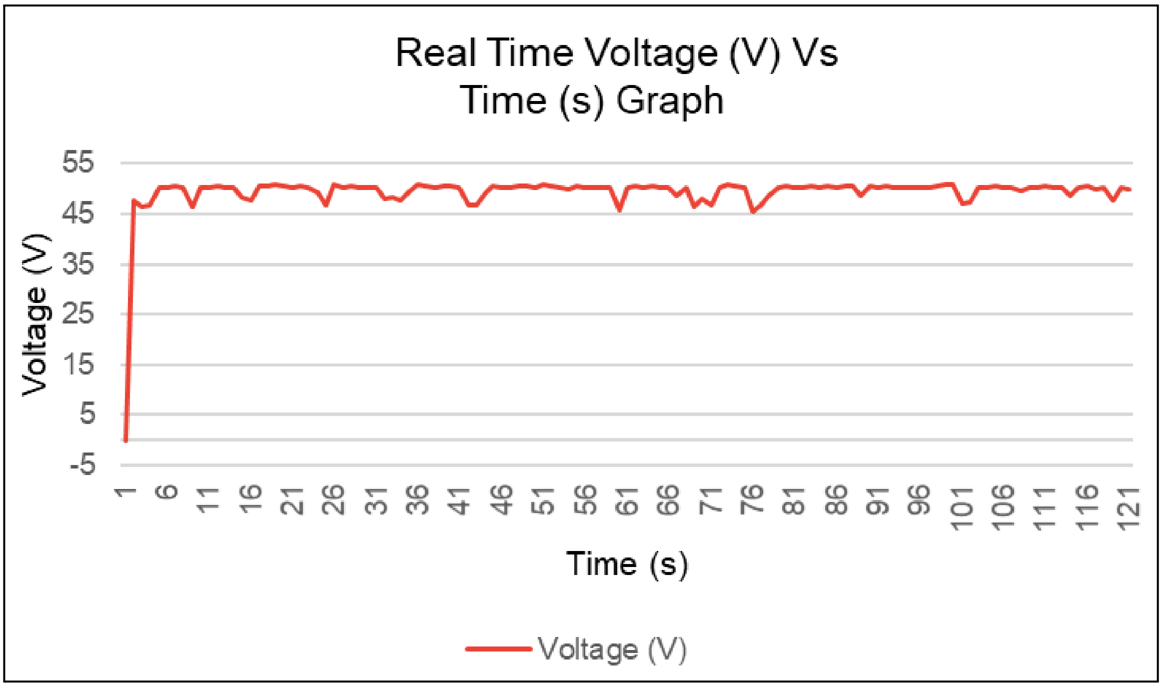


Figure 59: Supply voltage(V) to the motor vs time(s).

Here, we have demonstrated the real time voltage and current value fluctuations for 72 Kg load with respect to time in a graphical manner.

(Current and Voltage graph for 58 Kg load)

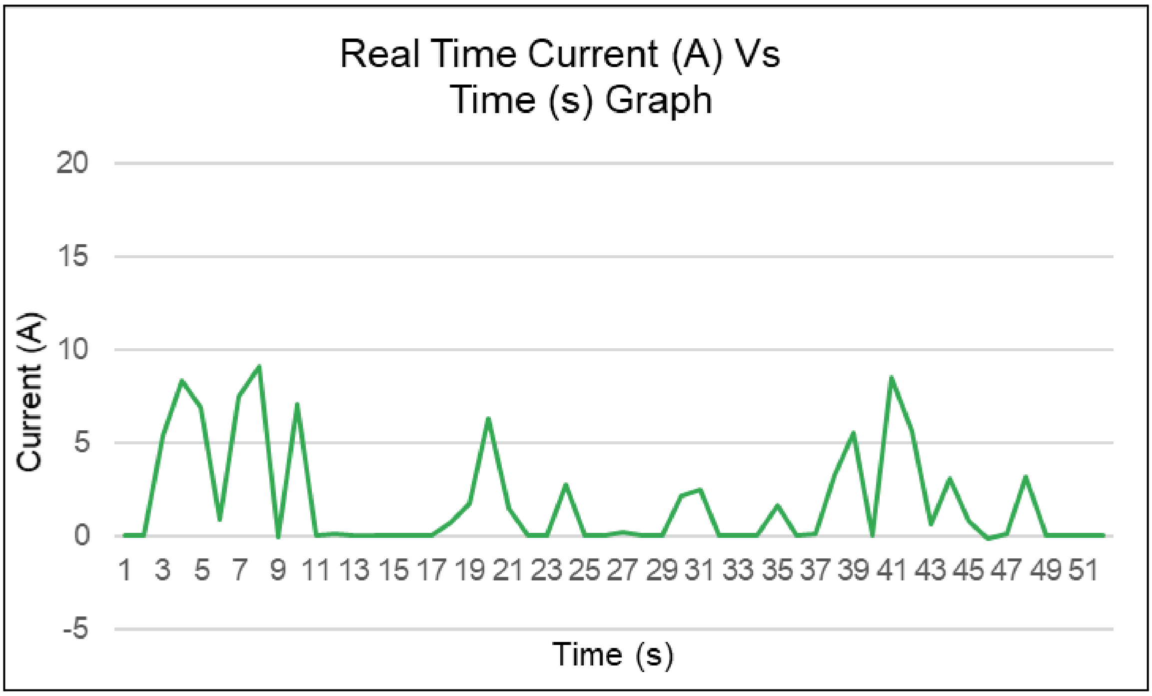


Figure 60: Supply current(A) to the motor vs time(s).

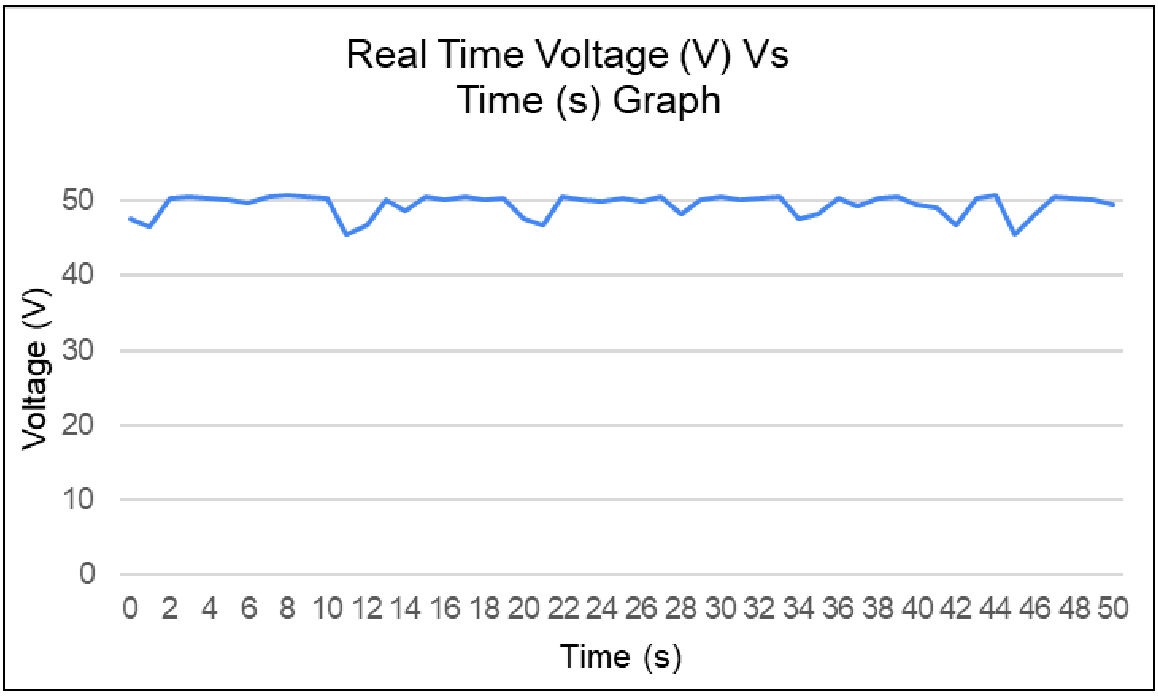


Figure 61: Supply voltage(V) to the motor vs time(s).

Here, we have demonstrated the real-time voltage and current value fluctuations for a 58 Kg load with respect to time in a graphical manner.

These graphs show us the time intervals for which we used regenerative braking and got back-fed energy from the motor. negative current values show us that region where we saved energy. Also, the nominal voltage is fluctuating in the normal range of the rated voltage for this li-ion battery.

5.3.10 Backup battery charging system using stationary solar panels:

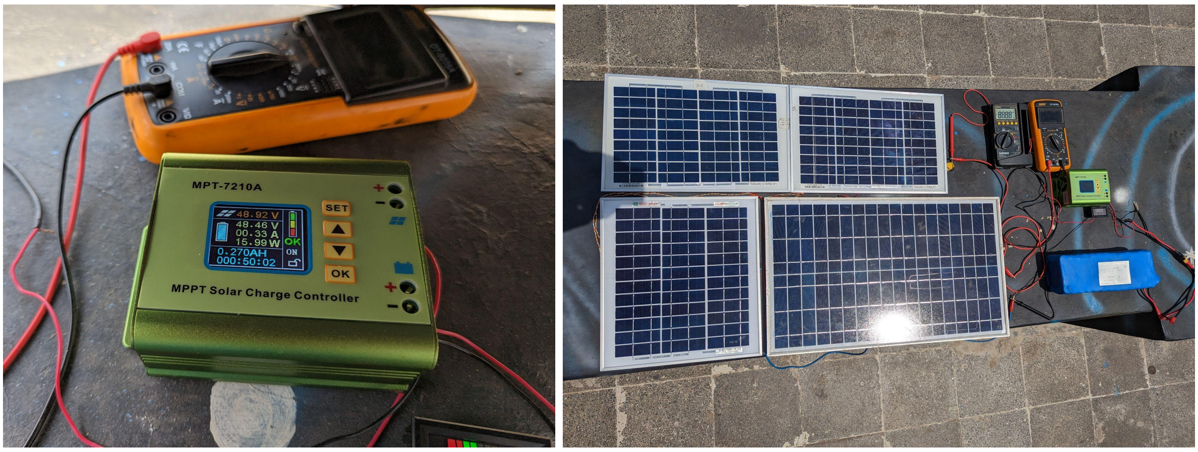


Figure 62: MPPT solar charge controller result at 50th minute and backup system construction

The project's solar charge system is being used as a backup energy source to slightly increase range. The battery's SOC and DOD were around 37.5% and 62.5% at the beginning. A 50W solar panel should theoretically take 8 to 9 hours to fully charge the battery from a condition of 37.5% SOC at this time. This test was conducted utilizing 50W of solar modules, with a 20W solar panel mounted in parallel and three 30W solar modules (each panel is approximately 10W) arranged in series. Additionally, the 20W panel has a Voc of 18V and Isc of 1.1amps, while the 10W panel's specifications are 18V of Voc and 0.65amps of Isc. As we know, parallel connections increase supply current whereas the series connections increase supply voltage. The test lasted for two hours and was conducted from 12.30 to 2.30 pm during the exact peak sun hours. Only a small portion of the battery percentage indication grew after that. The percentage of the battery is displayed in eight portions. Thus, we may roughly estimate that each segment holds about 12.5%. In conclusion, a battery's SOC grew by 1/8 of its total capacity, or around 12.5%, after about 2 hours of charging.

There is a constraint regarding availability of solar modules. First and foremost, we had to carry out the experiment using a 100W solar system. Unfortunately, we were forced to change our plans in order to work with 50W solar modules due to the lack of availability of this module. In comparison to the currently chosen modules, the 100W solar panel will increase supply current by twofold. The 48V, 10 amp battery will therefore take around 4 to 5 hours to fully charge from a level of 32.5% SOC when 100W of modules are used at peak solar hours. Working with 100W solar panels and incorporating a rapid charging technique into the idea would have been much more practical.

5.4 Analysis of mileage or covered distance by the e-bike with respect to the state of charge of the battery:

One of the significant portions of this ongoing project is to extend the mileage of the e-bike. From the field test, we are able to conclude the overall mileage of the system. At the very beginning, the test started to run from a fully charged battery without any additional backup charging facility. The test gave us a result that is very practical considering the real-life scenario.

From a completely charged state, the cycle traveled 22.6 km on the first ride. The e-bike then traveled roughly 21.7 kilometers. The e-bike provides us with a total mileage of 44.3 kilometers. Our project's mission statement has been to significantly increase the longevity of the mileage. The principal limitations of this experiment were the uneven conditions in which the test run was conducted throughout. The test run was done on an uneven, bumpy road rather than a smooth pitch road. This is one of the primary factors that forced the battery to use more amps in order to keep up with the current. However, if the test had been conducted in typical, completely constructed conditions, the outcomes would have been far better than they are now. As is well known, rough, muddy, or unmetalled roads require more power than those that are level and smooth.

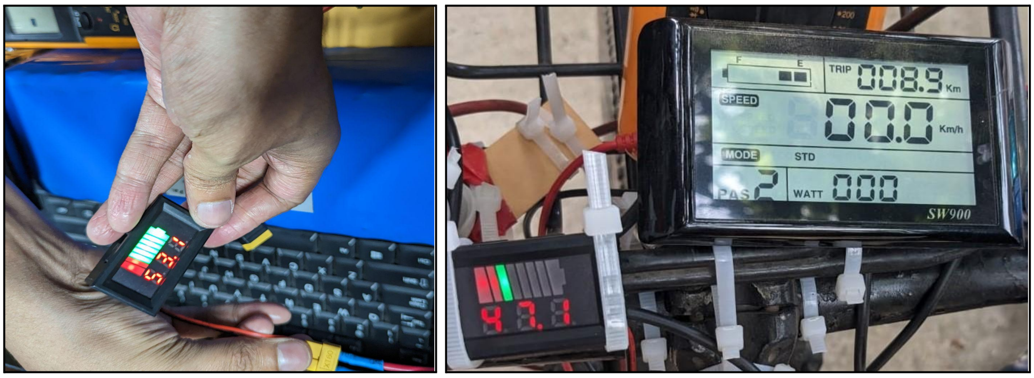


Figure 63: Battery percentage (%) and nominal voltage (V) in different states of usage.

5.5 Conclusion

In conclusion, the ideal solution, with the required adjustments, fully satisfies all of the project's objectives. The subsystems including, regenerating braking system, energy supply to the battery, control unit, backup battery charging systems are fully operational and operating. Special attention is also paid to the requirements of the stakeholders, and the prototype will be modified if the requirements change. The intended prototype has been produced for the demonstration after several tests and troubleshooting sessions.

Chapter 6: Impact Analysis And Project Sustainability [CO3, CO4]

6.1 Introduction

The use of electric bikes is an impactful idea with various terms of societal, health, safety, and economic benefits. The optimum design of the e-bike can have several possible outcomes that can shape many perspectives and ways of living of people. Project sustainability is a method that is becoming more and more popular for managing projects, programs, organizations, businesses, people, and other entities that require effective and efficient production, advertising, transportation, and the delivery of products and services. In general, from strategic planning through the planning phase, conceptualization, design, evaluation, funding, execution, surveillance, and assessment, specific metrics and criteria must be developed.

6.2 Assess The Impact Of The Solution

The use of electric bikes is an impactful idea with various terms of societal, health, safety, and economic benefits. The optimum design of the e-bike can have several possible outcomes that can shape many perspectives and ways of living of people.

- **Social & Economical Impact**

The world's electricity demands are increasing day by day as economic growth weakens and energy prices soar following Russia's invasion of Ukraine, After the Covid-19 pandemic global electricity demand is increasing rapidly, from then global electricity demand is expected to continue in a similar growth path into 2023, according to the IEA's report [29]. For all those reasons the gas price is increasing every day, so, clean energy transitions are the most effective and lasting response to the current crisis. At this time an electric bike can be a great solution to this problem as it does not need petrol or diesel. Using an e-bike can help to save a lot of money in the long run since it does not need any petrol or diesel. Also, e-bikes offer affordable batteries that last more than 5 years and can be used for a minimum of 10 miles even after charging fully[30].

- **Health and Safety**

Cycling can reduce inflammation and helps to reduce stress and anxiety, it has also been proven to prevent depression and gives the rider a sense of calm and peace[31]. E-biking is an aerobic exercise that can promote cell regeneration. Also, it can improve mental functioning. E-biking is a cardiovascular activity that helps to keep glucose and blood level under control as well[32].

- **Environmental Effect**

The opportunity cost of taking an e-bike is comparatively less than other, more polluting vehicles such as petrol cars. As a transportation system, an e-bike is arguably the best thing for the environment rather than a car or other transport. In fact, the carbon footprint is 50 times smaller per kilometer than that of a car. But bicycle batteries can be bad for the environment. Though harmful chemicals can be emitted during battery production, the batteries are durable and can last up to 5 years, or 500 to 100 charges[1]. Moreover, the environmental impact remains low because the batteries are efficiently recycled as most of the material from each battery gets reused. We used a lithium battery which is almost completely recyclable. Nevertheless, it is unfortunate there has not been much innovation in the market that has catalyzed lithium batteries so, most of them are reused rather than recycled. According to studies, only 5% of batteries are recycled[25][26]. However, this number will be increasing because of the studies that have been done also by startups to solve this problem.

● **Legal And Cultural Impact:**

Using an e-bike can never cause any harm in terms of legal and cultural aspects of our society. We know that according to regulation 74, sub-regulation 1, clause (a), sub-clause (i) electric vehicles having motor power less than 5kw do not fall under any regulations of registration, so, if the bike is used with rider's safety and cautions in mind, there shouldn't be any extra hassle for the user[27]. Moreover, considering different social norms it has more acceptance within our society compared to other motorized vehicles.

6.3 Evaluate The Sustainability

SWOT Analysis

For any design-based project one of the most important and essential parts is its sustainability assessment. Based on this analysis and the common grounds of the three designs one can acquire an overall knowledge about the strengths, weaknesses, opportunities, and threats of the project.

6.3.1 SWOT Analysis For Optimal design

Strength	**Weakness**
1. Zero emission from the vehicle. 2. Owning a vehicle that costs less. 3. Very low maintenance. 4. Energy savings is achievable 5. Easy mechanism and user-friendly.	1. The vehicle needs time to recharge. 2. Battery life is short and its replacement is costly. 3. A lack of charging infrastructure.
Opportunity	**Threat**
1. Usage of Fossil fuels can be reduced. 2. Governments subsidy for ownership. 3. Zero tax credit.	1. The potential rise of the electricity price. 2. Competition with cheaper hybrid cars and hydrogen fuel vehicles. 3. Two-wheeler vehicles are less safe on busy roads.

Table 25: Swot Analysis For Optimal Design

- **Strengths:**

    - **Zero emission from the vehicle**: Electric bicycle, whether it has a single source or multiple or hybrid source system, during the vehicle's operations it doesn't emit any greenhouse gas or any toxic materials into the environment. It is overall an environment-friendly system.

    - **Owning a vehicle that costs less:** Usually owning any vehicle costs the owner a lot. Owning a vehicle demands having a place for it, and paying taxes, fees, and license fees every year. But in terms of e-bikes, we don't need to give any license fees for them, and as it is a lower maintenance vehicle that also costs less than any car or bike, owning it will be very cheap in comparison.

    - **Very low maintenance:** One of the strongest advantages of having a two-wheeler e-bike is that it has very low maintenance. Very little mechanical parts maintenance is needed here and also it can have less damage to the braking pad in the long run if regenerative braking is used.

    - **Energy savings is achievable:** There is a strong chance of saving the energy of the battery through various processes. If the owner uses a hybrid source for the bike then 5%-20% of the battery power can be saved overall. Regenerative braking is another method of saving a battery's power using the back EMF of the motor.

    - **Easy mechanism and user-friendly:** The whole mechanism is very straightforward and easy to operate compared to combustion engine bikes or cars. So, people of every age can use it effortlessly most of the time.

- **Weaknesses:**

    - **The vehicle needs time to recharge:** In most cases, e-bikes use Li-ion batteries as the source of the bike. No matter how big the power (watt) is delivered by a wall charger, it will still take a considerable amount of time to change the vehicle as the battery is mostly more than 200+ watts in power. So it is a major weakness indeed.

    - **Battery life is short and its replacement is costly:** The battery of a bike has a lower life cycle in general. In around 4-6 years the battery of the bike might need a replacement depending on the use of the bike. Also to replace the battery the owner needs to buy a new battery which is costly.

    - **A lack of charging infrastructure:** Most of the well-developed countries don't have the facility of well-built e-bike charging stations. Bangladesh also lacks charging stations infrastructure, as a result, charging in between road trips is not possible here.

- **Opportunities:**

    - **Usage of Fossil fuels can be reduced.:** Day by day the cost of fossil fuels is increasing globally, and as a result, people are engaging towards electric vehicles more and more. So there is a great opportunity for e-bikes to emerge as the main transportation choice for most regular citizens.

    - **Government's support:** Gradually the demand for e-bikes is increasing rapidly in our society. People are accepting it as a reliable source of transportation for their needs. As a result, the government is acknowledging this outcome in a positive way. So hopefully we will have the opportunity to get the government's support in e-bike designs and manufacturing processes in the future.

    - **No tax for e-bikes:** Usually e-bikes have no tax payment system according to the government's rules. Because e-bikes have less powerful motors in comparison to combustion engine vehicles, it doesn't need any license and tax fees. This can also be an opportunity for the market for e-bikes to grow.

- **Threats:**

    - **Potential rise of the electricity price:** There is a great chance of cost increase in power generation in Bangladesh. If that happens, charging costs will also increase and in the long run, it will affect the e-bike owner negatively in terms of expenditures of the bike.

    - **Competition with cheaper hybrid cars and hydrogen fuel vehicles:** It is a great threat for the e-bike industry to have a competitive market of hybrid vehicles. As the number of hybrid and hydrogen cars is increasing and also their prices are decreasing, it is only a matter of time before this will be a threat to the overall e-bike manufacturing market.

    - **Two-wheeler vehicles are less safe on busy roads:** In compassion with quad-wheeler or three-wheeler vehicles, two-wheeler e-bikes will have less safety and balance. As it doesn't have a wide and strong build structure and stays unguarded from other vehicles, it is comparatively risky in busy areas.

6.4 Conclusion

Economic sustainability is the ability to justify environmental demands from both people and businesses without harming the environment's ability to support future generations. An electric bike that we have designed and customized is for consumers who need to use a transport system on a daily basis for work purposes or to do daily chores. To summarize, this chapter discusses how this project can be impactful if we manage to modify the e-bike and make it a user friendly and easy to assemble system that can provide enough mileage for everyday use and costs less in the long run.

Chapter 7: Engineering Project Management [CO11, CO14]

7.1 Introduction

The process of managing a project from inception to completion involves applying the necessary knowledge and skills to keep it on track with all relevant requirements, within budget, and on schedule. A project's objectives must be clearly specified very early on while rigorously following a predetermined schedule for the project's development. Project management assists us in defining the strategy for achieving the project's goals, as well as its specific processes and deliverables. Along with managing project-related tasks, management also entails ensuring regular communication between the project's participants and other relevant stakeholders. The next step is to create contingency plans for unanticipated emergencies. When the project's demonstration is conducted according to the predetermined time frame, project management proficiency is clearly demonstrated.

7.2 Define, Plan And Manage Engineering Project

- **FYDP - P**

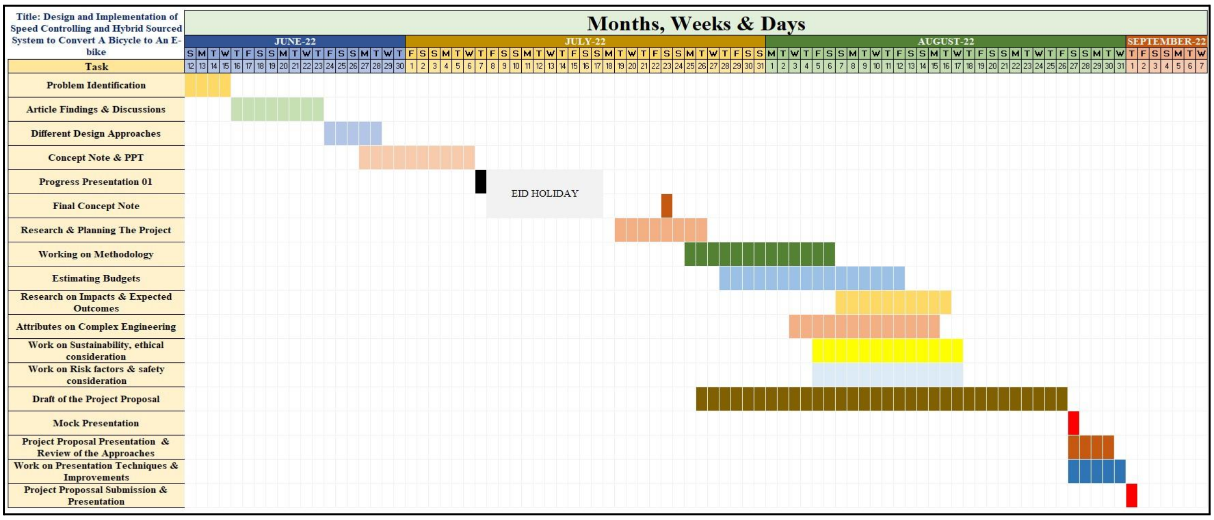


Figure 64: Gantt Chart for EEE400P

Tasks	Start Date	End Date	Duration (Day)
Problem Identification	12.06.22	15.06.22	4
Article Findings & Discussions	16.06.22	23.06.22	8
Different Design Approaches	24.06.22	28.06.22	7
Concept Note & PPT	27.06.22	06.07.22	11
Progress Presentation 01	07.07.22	07.07.22	1

Final Concept Note	21.07.22	21.07.22	1
Research & Planning The Project	19.07.22	26.07.22	8
Working on Methodology	25.07.22	06.08.22	13
Estimating Budgets	28.07.22	12.08.22	14
Research on Impacts & Expected Outcomes	07.08.22	16.08.22	10
Attributes on Complex Engineering	03.08.22	15.08.22	13
Work on Sustainability, ethical consideration	05.08.22	17.08.22	13
Work on Risk factors & safety consideration	05.08.22	17.08.22	13
Draft of the Project Proposal	26.08.22	26.08.22	1
Mock Presentation	27.08.22	27.08.22	1
Project Proposal Presentation & Review of the Approaches	27.08.22	30.08.22	4
Work on Presentation Techniques & Improvements	27.08.22	31.08.22	5
Project Proposal Submission & Presentation	01.09.22	01.09.22	1

Table 26: Gantt Chart Timeline For EEE400P

- **FYDP - D**

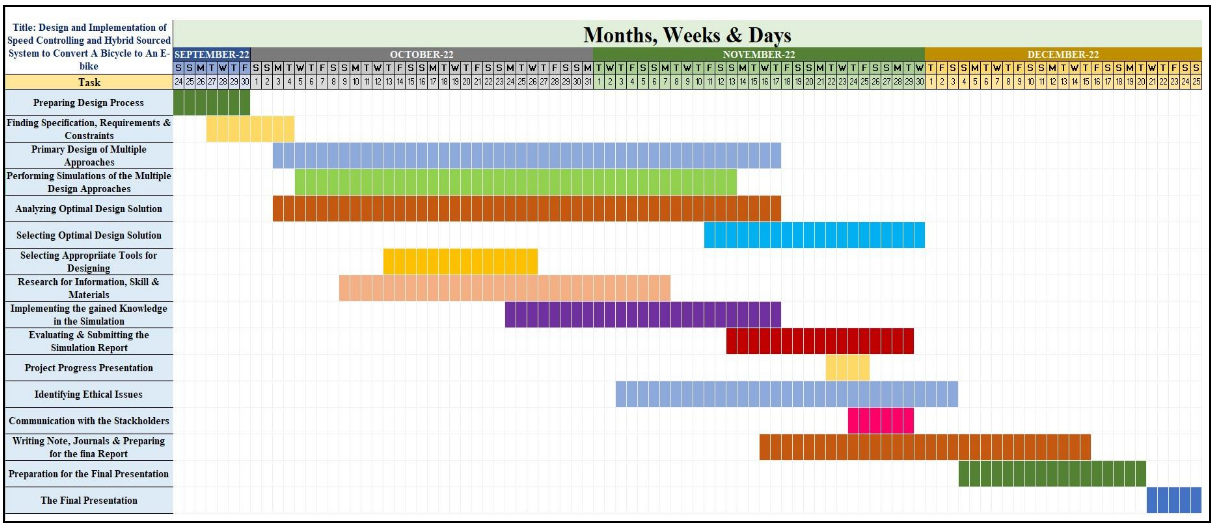


Figure 65: Gantt Chart For EEE400D

Tasks	Start Date	End Date	Duration (Day)
Preparing Design Process	24.09.22	30.09.22	7
Finding Specification, Requirements & Constraints	27.09.22	04.10.22	8
Primary Design of Multiple Approaches	03.10.22	10.10.22	8
Performing Simulations of the Multiple Design Approaches	05.10.22	15.10.22	11
Analyzing Optimal Design Solution	03.10.22	17.10.22	15
Selecting Optimal Design Solution	13.10.22	18.10.22	6
Selecting Appropriate Tools for Designing	13.10.22	26.10.22	14
Research for Information, Skill & Materials	09.10.22	07.11.22	30
Implementing the gained Knowledge in the Simulation	24.10.22	17.11.22	25
Evaluating & Submitting the Simulation Report	13.11.22	29.11.22	17
Project Progress Presentation	22.11.22	25.11.22	4
Identifying Ethical Issues	03.11.22	03.11.22	1
Communication with the Stakeholders	24.11.22	29.11.22	6

Writing Note, Journals & Preparing for the final Report	16.11.22	15.12.22	30
Preparation for the Final Presentation	04.12.22	20.12.22	17
The Final Presentation	21.12.22	25.12.22	5

Table 27: Gantt Chart Timeline For EEE400-D

- **FYDP - C (Approximate)**

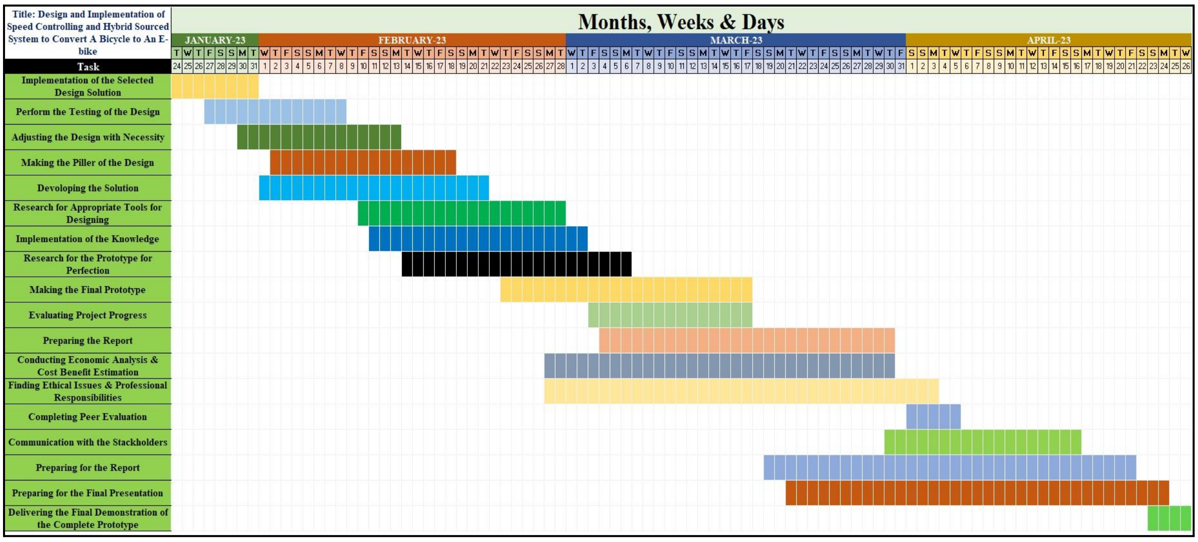


Figure 66: Gantt Chart For EEE400C

Tasks	Start Date	End Date	Duration (Day)
Implementation of the Selected Design Solution	24.01.23	31.01.23	8
Perform the Testing of the Design	27.01.23	08.02.23	13
Adjusting the Design with Necessity	30.01.23	13.02.23	15
Making the Pillar of the Design	02.02.23	18.02.23	17
Developing the Solution	01.02.23	21.02.23	21
Research for Appropriate Tools for Designing	10.02.23	28.02.23	19
Implementation of Knowledge	11.02.23	02.03.23	19
Research for the Prototype for Perfection	14.02.23	06.03.23	21

Making the Prototype	23.02.23	17.03.23	23
Evaluating Project Progress	03.03.23	17.03.23	15
Preparing the Report & Final Prototype	04.03.23	30.03.23	27
Conducting Economic Analysis & Cost Benefit Estimation	27.02.23	30.03.23	32
Finding Ethical Issues & Professional Responsibilities	27.02.23	03.04.23	36
Completing Peer Evaluation	01.04.23	05.04.23	5
Communication with the Stakeholders	30.04.23	16.04.23	18
Preparing for the Report	19.03.23	21.04.23	34
Preparing for the Final Presentation	21.03.23	24.04.23	35
Delivering the Final Demonstration of the Complete Prototype	23.04.23	26.04.23	4

Table 28: Gantt Chart Timeline For EEE400-C

7.3 Evaluate project progress

To start the evaluation of this project we were considering two types of test and observation of the prototype building. At first we needed to assemble all the components in a trainer board format and connect the controller with the motor and use the 48V 10Ah battery as the power supply. We attached the controller, throttle, speedometer and the electric brakes on a board and connected all the components to test them. We put the motor wheel on a metal stand for it to run freely on the stand. So, the trainer board testing is for the free wheel test without any load(cycle weight and rider weight) connected. After that we measured the values of wheel speed, supply voltage to the motor, and supply current to the motor both using and not using electric brake/regenerative brake. We then calculated the total energy consumption from the battery for both situations. We noticed some visible differences between the two values over the course of time. When regenerative braking is used, current supply is rapidly decreased to 0 within 2-3 seconds of braking which saves a certain amount of energy compared to when it's not used. As we previously observed, by using regenerative braking we could save 455.166 J of supply energy over the course of 120 seconds during the free wheel test with no load condition so after the tests without any load we needed to do some real world field tests with different loads to observe the current and energy consumption of the motor.
So, we did some field tests on the road with a rider weighing about 72 kg and measured the values of supplied current and traveled distance with the optimum speed depending on the road conditions. We tested the current consumption and calculated the energy consumption of

the motor through the controller by using both regenerative braking and traditional friction braking. Then measured the current and consumed energy for a smaller load of 58 kgs and observed the difference between this results from the previous results. We got some visible difference between these two energy graphs of two different loads. Also we obtained the graphs of energy consumption with regenerative braking and also with traditional friction braking and comparing their performance with respect to time. Moreover, we measured the real time current and voltage data and observed the effect through graphs. By this manner we could demonstrate our performance analysis of using regenerative braking on an e-bike.

7.4 Conclusion

Nearly every project will undoubtedly run into problems at some point, thus engineering project leaders must be ready to address these problems head-on and offer practical solutions. If anything goes wrong with the project, the engineering project coordinator must address the root causes of these mistakes and employ problem-solving methods to get the project back on track. Additionally, the project may be run easily and appropriately with the assistance of occasional supervision from ATC panel members.

Chapter 8: Economical Analysis [CO12]

8.1 Introduction

Economic analysis is a crucial component of any product study. It is employed to assess the advantages and disadvantages of the project's output. It provides the pioneers with a broad overview of how viable and marketable the project product is. Regardless of the many goals of such analysis, assessing and foreseeing customer reactions to a product is a crucial component of it. They could include making a profit, and it clarifies how business outcomes will turn out.

8.2 Economic Analysis

In the current scenario the motorbike market in Bangladesh is much bigger and this is a big opportunity to grab this enormous opportunity of introducing an environment-friendly e-bike. The statistics show that around 0.67904 million units of motorbikes have been sold and about 1.5 billion USD in revenue have been collected in the year 2018. And it is estimated that around 0.82259 million units of motorbikes will be sold in the year 2026, in which 2.74billions of USD will be earned as revenue[28]. This e-bike project has that much potential to enter the market as it provides both a certain range of miles and cost-effectiveness. The motorbikes that are available in the market are categorized in terms of off-road, on-road, and scooters. And the proposed project works both on and off-road. Moreover, the market only has 0.6% of e-bikes of the total number which is not really a good sign in terms of the health of the environment[28]. To conclude, the introduction of this new variant of an e-bike will serve in both cost-effective and better-performance cases.

8.3 Cost-Benefit Analysis

A cost-benefit analysis is used to determine whether the project is viable or not. A component of economic analysis has its advantages and disadvantages as well. A project's advantages provide accurate, quantitative direction when decisions related to product developments are executed correctly under accurate assumptions. A project does not have to be completed at the lowest possible cost to be economical. The effectiveness, performance, and durability of the project components and the feasibility are the most important aspects. A product has to be precise to be usable. Since the market offers a wide range of components and the necessary chassis designs makes it more challenging to choose appropriate components in terms of price and performance. We as an engineer must have to choose the components that are simultaneously cost-efficient and effective for the project. Every component that we used for the project has a certain level of pros and cons. We have considered three approaches. First, among the approaches some of the components cost more than others but we had to choose wisely since we need the most efficient components for different uses. If we compare the components and the approaches it will be easier to understand the comparison.

- **Approach 01**

Component	Price	Strength	Weakness
Motor controller with regenerative Braking System full kit	12,000	3-mode sine wave motor controller can rotate in both directions and this ensures charging up the battery	Availability is very low and costly

Table 29: Core Components Analysis For Design-1

- **Approach 02**

Component	Price	Strength	Weakness
Hub motor controller with kit	5572	Compact size and efficiently controls the speed of the motor.	Six wires throttle is not supported in this controller
DC Dynamo	520	Produces electric energy from kinetic energy on a constant basis	Needs frequent change of dc dynamo
DC-DC Converter	380	Prevent damages from any kind of breakdown of the device	Inadequate due to constant change of supply voltage and current

Table 30: Core Components Analysis For Design-2

- **Approach 03**

Component	Price	Strength	Weakness
Hub motor controller with kit	5572	Compact size and efficiently controls the speed of the motor.	Single voltage BLDC motor controller and does not support complex LCD equipment expansion

Cadence sensor for pedal assist	2,100	Senses the rotation of the motor to start or turn off the motor to help with pedal assist.	Magnet ring gets attracted to dirt very quickly, which is an obstacle to sending a strong signal to the PAS sensor

Table 31: Core Components Analysis For Design-3

8.4 Evaluate Economic And Financial Aspects

According to the given budget and the specification of this project, it clearly gives an opportunity to expand the electric bike market in Bangladesh at a low cost. Commercially this project is very much possible to manufacture in a cost-effective manner and also to procure for the mass people. Moreover, this project has an edge over the conventional e-bikes that are currently available in the market for the regenerative braking system that usually allows it to extend its range for certain miles by only pressing regenerative enabled brakes. Furthermore, the extra backup system is something that really puts a heavy weight on the range that is one of the core objectives of this project.

Quantity	Component	Approximate Price(BDT)	Products Link Address
1	Lithium-Ion Battery	20,000	https://bangladesh.desertcart.com/products/16026861-vpower-hk-lithium-ion-battery-48-v-20-ah-e-bike-electric-bicycle-rechargeable-battery-packs
1	BLDC Hub Motor	16,000	https://www.daraz.com.bd/products/1000w-48v-high-quality-hub-motor-kit-for-e-cycle-i190600911-s1283961607.html?dsource=share&laz_share_info=20354408_100_100_1302530_19857942_null&laz_token=13982747dfacd01ce549296157333eb4
1	Motor Controller with regenerative Braking System full kit	12,000	https://www.daraz.com.bd/products/1000w-48v-high-quality-hub-motor-kit-for-e-cycle-i190600911-s1283961607.html?dsource=share&laz_share_info=20354408_100_100_1302530_19857942_null&laz_token=13982747dfacd01ce549296157333eb4

1	Head Light	350	https://www.daraz.com.bd/products/waterproof-rechargeable-2-in-1-bicycle-light-and-horn-many-others-colour-bicycle-horn-light-i180732236-s1148768155.html?spm=a2a0e.searchlistcategory.list.25.76a05022XXvQyb&search=1
1	Chassis	4,500	
		Total: 52,850	

Table 32: E-bike Budget for optimal design approach.

- **Alternative Approach 2:**

Quantity	Component	Approximate Price(BDT)	Products Link Address
1	Lithium-Ion Battery	20,000	https://bangladesh.desertcart.com/products/16026861-vpower-hk-lithium-ion-battery-48-v-20-ah-e-bike-electric-bicycle-rechargeable-battery-packs
1	BLDC Hub Motor	16000	https://www.daraz.com.bd/products/1000w-48v-high-quality-hub-motor-kit-for-e-cycle-i190600911-s1283961607.html?dsource=share&laz_share_info=20354408_100_100_1302530_19857942_null&laz_token=13982747dfacd01ce549296157333eb4
1	Motor Controller	5572	https://www.daraz.com.bd/products/48v-60v-72v-3000w-hub-motor-controller-24mos-max80a-for-electric-bike-e-scooter-motorcycle-bldc-motor-controller-i236477323.html
1	DC Dynamo	520	https://www.daraz.com.bd/products/775-motor-dc-12v-21000rpm-high-power-motor-i134608286.html
1	DC-DC Converter	380	https://www.daraz.com.bd/products/boost-converter-xl-6009-dc-dc-step-up-module-with-adjustable-booster-power-supply-module-i128660478.html

1	Head Light	350	https://www.daraz.com.bd/products/waterproof-rechargeable-2-in-1-bicycle-light-and-horn-many-others-colour-bicycle-horn-light-i180732236-s1148768155.html?spm=a2a0e.searchlistcategory.list.25.76a05022XXvQyb&search=1
1	Chassis	4500	
		Total: 47,322	

Table 33: Budget on approach 2

- **Alternative Approach 3:**

Quantity	**Component**	**Approximate Price(BDT)**	**Products Link Address**
1	Lithium-Ion Battery	20,000	https://bangladesh.desertcart.com/products/16026861-vpower-hk-lithium-ion-battery-48-v-20-ah-e-bike-electric-bicycle-rechargeable-battery-packs
1	BLDC Hub Motor	16,000	https://www.daraz.com.bd/products/1000w-48v-high-quality-hub-motor-kit-for-e-cycle-i190600911-s1283961607.html?dsource=share&laz_share_info=20354408_100_100_1302530_19857942_null&laz_token=13982747dfacd01ce549296157333eb4
1	Motor Controller	5572	https://www.daraz.com.bd/products/48v-60v-72v-3000w-hub-motor-controller-24mos-max80a-for-electric-bike-e-scooter-motorcycle-bldc-motor-controller-i236477323.html
1	Cadence sensor for pedal assist	2,100	https://www.amazon.com/-/es/Bicicleta-el%C3%A9ctrica-Assist-Sistema-modificadas/dp/B094925HYN/ref=sr_1_3?keywords=pedal%2Bassist%2Bsensor&qid=1660824306&sr=8-3&th=1

1	Head Light	350	https://www.daraz.com.bd/products/mpt-7210a-2436486072v-color-lcd-dc-dc-mppt-solar-panel-charge-controller-i204493938-s1152542940.html?spm=a2a0e.searchlist.list.1.3efc55a8zHU2Rs&search=1
1	Chassis	4,500	
		Total: 48,522	

Table 34: Budget on approach 3

- **Backup battery charging components (Considered for all approaches)**

4	Solar Panel	10,004	https://www.daraz.com.bd/products/50-watt-12-volt-solar-panel-i169196383.html
1	Solar Charge Controller	6250	https://www.daraz.com.bd/products/mpt-7210a-2436486072v-color-lcd-dc-dc-mppt-solar-panel-charge-controller-i204493938-s1152542940.html?spm=a2a0e.searchlist.list.1.3efc55a8zHU2Rs&search=1
		Total: 16,254	

Table 35: Backup System Budget

The controller price, the cadence sensor, and the DC dynamo are the primary distinctions between approach-01 and the other approaches. The 3-sine wave controller price is around BDT12,000, which can enable regenerative braking. Although we can see that the price of approach-01 is a little higher than the prices of the other two methods, we decided to go with the regeneration enabled system because of its performance and long-term advantages. By just activating the regenerative system, this system can backfeed a specific amount of energy to the battery, so extending the range. In this situation, we place our faith in a system that can guarantee significantly improved performance while ignoring the system's cost. To conclude, the backup solar system is mandatory for all three approaches.

8.5 Conclusion

It is clear that a product's long-term viability depends not only on the effectiveness and performance of the system but also heavily on the accessibility of the product as a consequence of the sensible economic choices made for the product. We may more completely evaluate the many compromises required to increase the project's sustainability and accessibility with the use of economic research. Thus, it is crucial that an extensive analysis be conducted concurrently with the project's development.

Chapter 9: Ethics And Professional Responsibilities [CO13, CO2]

9.1 Introduction

Ethical consideration is important to attach to ethical norms in papers or articles because it promotes the goal of the research and helps to prohibit the falsifying and misrepresenting of research data. Since research frequently requires a considerable lot of collaboration and coordination among many various users from many fields and organizations, ethical standards promote the values that are vital to collaborative work. Also, many of the ethical rules aid in holding researchers responsible to the public. Constitutional provisions on research misconduct, conflicts of interest, human subjects protections, and animal care and usage, for example, are required to ensure that researchers sponsored by public funds may be held accountable to the public. Both the ethical and Professional responsibilities help in making the project more acceptable.

9.2 Identify Ethical Issues And Professional Responsibility

According to The shopping guide to bikes, a number of ethical issues associated with bikes and e-bikes including carbon emissions have been mentioned. From the traffic ethical point of view, one of the most important reasons is traffic accidents. In addition, the device-level mechanism of an e-bike is needed to transport the premise of ethics. Some of the ethical considerations of this project are

- **Battery disposal**

In terms of battery disposal, it should be a major consideration since most e-bike brands do not produce batteries and motors used for e-bikes but rely on brands like Bosch, Panasonic, and Samsung, and Sony and others. Regular use of batteries will also have an effect on the battery life. From the extraction process to disposal there are several significant environmental impacts. Which also should be considered under professional responsibilities [25][26].

- **Stakeholders**

According to Navigation research, global sales of e-bikes are expected to grow nearly 32 million to 40 million from 2014 to 2023 under a base scenario[21].
Innovative trends will be continued for market growth. The hybrid system has also been introduced to the market even though from Bangladesh's perspective the increase rate is not as much as in other countries. Some bicycle manufacturers are importing e-bikes from China and European countries since it does not require any driving license or registration [22]. Its popularity is increasing day by day according to the Duratanta bicycle's showroom manager. He said, people are choosing e-bikes over regular bicycles for their regular commuting, users are happy as the e-bikes are cheaper, and most importantly there is no need for fuel.

9.3 Apply Ethical Issues And Professional Responsibility

- **Physical safety protocols**

1. **Position of the battery:**

Most electric bicycles use lithium batteries that are highly ignitable, and most of them occur because of careless treatment. Also, an important thing to notice is the position of the battery. Most of the e-bikes are manufactured in a way where the battery is positioned just below the seat which could be really dangerous if the battery catches fire. Hence, we are designing a system in such a way that the battery stays put away from the seat.

2. **Motor control failure:**

In case of a motor failure for an e-bike it is safer to keep an alternative option, for that we are going to use a small backup motor controller, bolted to the bottom of the cruiser paralleled with battery and control signal wires.

3. **Throttle malfunction:**

In some cases, throttle cable may stretch as a result the throttle does not respond. Also, by overusing the throttle control, it may get stuck when the throttle is pulled back and will not return to the off position on its own. If a rider does this repeatedly it will eventually loosen or get damaged. If this happens on a ride and the bicycle remains at full speed this may cause an accident[30].

4. **Malfunctions of the pedal assist system:**

Malfunctions of the power or pedal assist system may cause issues related to the pulsating or power cut-offs. The reason for such issues could be the ring of magnets on the sprockets due to being knocked around.

Risk Events	Management Procedure	Contingency Plan
Position of the battery	A mid frame battery is positioned since it can give a great balance to the whole system and is the safest.	We are planning to add a protective shield that will cover the battery and save the rider from getting blazed
Motor control failure	By resetting the controller, initial troubleshooting can be possible.	Addition of a manual override switch to allow manual control if needed.
Throttle malfunction	Rider must start off slowly and ease into the throttle.	By adding an emergency power disconnect switch that goes through the controller to the battery[30] accidents can be avoided.

Malfunctions of the pedal assist system	The main reason for such issues is occasional power cut offs and using the ring magnets on the front sprocket which was avoided while building the prototype.	By adjusting the pedal assist magnet position disc nearer the sensors, we can solve the problem.

Table 36: Risk Management

- **Commercially approved components**

It is important that only globally approved components are used in the system, which ensures that the e-bike does not harm users.

- **Ensuring accessibility to the mass**

One of the main goals of the project was to make sure that the system is cost efficient so that the accessibility of the e-bike with regenerative braking system is increased to a larger demographic.

9.4 Conclusion

To conclude the chapter it can be said that with the appropriate ethical and professional considerations the prototype can be used by the users safely but the users have to make sure that they are always visible by keeping distance or using a bell, also, they should pay a closer attention to the traffic law.

Chapter 10: Conclusion And Future Work

10.1 Project Summary / Conclusion

In this project, a small energy vehicle with a regenerative braking system is designed. In recent years, the automotive system has favored brushless DC motors due to their advantageous properties, including electronic commutation and ease of operation. Regenerative braking, which saves energy when braking, is not part of the existing system. Additionally, some systems, like the one with this capability, include boost converters, which raise the price and system size. Therefore, a flexible method that does not utilize a boost converter is suggested and empirically confirmed. An extensive and detailed discussion is provided to highlight the shortcomings and expense of the traditional braking method and also the other methods like dynamo and motor controller with pedal assists system.

The research first focuses on simulated results and then compares the performance among all three designs, comparing control mechanism, budget, usability, sustainability, and impact. We chose an optimal design which is a design with a regenerative braking system. Each of the units is separately tested and the motor is operated also the SOC is compared among three of the designs. Finally, the braking current at various speeds and the braking current time are measured. Regenerative braking will undoubtedly decrease energy use for charging the battery from the source and will recharge the batteries while operating.

10.2 Future Work

Laboratory experiments have been used to demonstrate the regenerative braking system. Furthermore, the necessary data is gathered under constant load conditions, but the actual situation will vary because the load varies in various circumstances.

However, in the future, based on the proposed research work, analyzes of the engines of various high-rated vehicles can be carried out. Currently, we are using the commonly used Sensorless BLDC motor control which is sometimes called sensorless trapezoidal control of BLDC motors which uses back EMF (BEMF) for determining the location of the motor's rotor. We can use further improved motor controllers like using ‘Fuzzy logic controllers with less loss and better speed-controlling accuracy to improve overall performance. The inclusion of a ‘Torque sensor-based pedal assist system’ can further improve the performance of the e-bike as well. Also, it can be marketed in order to make braking energy available on a larger scale. Exploring this work from a commercial perspective, therefore, becomes a lucrative area of research. Additionally, in the future different types of motors can be used to improve the design which can be more effective as a back emf generator. Regenerative braking will be included into new drive train designs, thus energy loss will be reduced in electric systems. Furthermore, the inclusion of a better-performing battery like lithium-phosphate can improve the performance of the bike in future iterations of the design as well. Finally, serial

RBS(Regenerative Braking System) is way more efficient than parallel RBS(Regenerative Braking System). This newly developed mechanism deals with brake lever position or the angle of the brake to enable the friction brake when needed. When the pressure of the brake reaches a certain level or reaches a certain level of the angle of the lever then it activates the friction brake. Serial RBS(Regenerative Braking System) needs VSE(Vehicle State Estimator) to calculate the data of speed, road traction and the position of the vehicle.

Chapter 11: Identification Of Complex Engineering Problems And Activities

11.1 Attributes of Complex Engineering Problems (EP)

	Attributes	**Put tick (√) as appropriate**
P1	Depth of knowledge required	√
P2	Range of conflicting requirements	
P3	Depth of analysis required	√
P4	Familiarity of issues	
P5	Extent of applicable codes	√
P6	Extent of stakeholder involvement and needs	
P7	Interdependence	

Table 37: Attributes Of Complex Engineering Problems

11.2 Reasoning how the project address selected attribute (EP)

P1. Depth of knowledge required: An immense amount of knowledge is required regarding this project's completion. Our group members have gone through a lot of publications to gather ideas about this project. Moreover, we the members have identified the requirements and specifications regarding the project. Furthermore, we have deciphered the aspects of its sustainability. Finally, we have measured the impacts of our project exploring journals to counter the obstacles we are facing in the present day. This will lead us toward the success we are aiming for.

P3. Depth of analysis required: We have gone through research articles for a better understanding of our project. This led us towards three different approaches to work on. This extensive amount of work on the literature review showed us the path to create something like a regenerative braking controller for e-bikes.

P5. The extent of applicable codes: For the completion of our project requires some standard ratings following these systems like braking system, motor wattage, etc. These standards must be followed to avoid any sort of unwanted scenario.

11.3 Attributes Of Complex Engineering Activities (EA)

	Attributes	**Put a tick (√) as appropriate**
A1	Range of resource	√
A2	Level of interaction	√
A3	Innovation	
A4	Consequences for society and the environment	√
A5	Familiarity	

Table 38: Attributes Of Complex Engineering Activities

11.4 Reasoning How The Project Address Selected Attribute (EA)

A1. Range of resources: Working on several research papers and articles we came up with three different approaches. From these approaches, we will study and simulate to find out the efficiency and finally, we will choose one of these as our optimal one.

A2. Level of interaction: One of the key points is to gather the idea of the field in respect of our project. So, we have interacted with some of the stakeholders and given a close look at the current situation from the perspective of our country.

A4. Consequences for society and the environment: Our e-bike project is a hybrid system that allows multiple power sources that excludes carbon-emitting systems. Also, these systems have very low noise that plays no role in sound pollution. So, our project is very environmentally friendly and will play a significant role in climate change.

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Appendix

The code of P&O method used for the purpose of utilizing MPPT Algorithm:

```
function D = fcn(VA, IA)
persistent VAprev
persistent PAprev
persistent Dprev

if isempty(VAprev)
      VAprev = 0;
end
if isempty(PAprev)
      PAprev = 0;
end
if isempty(Dprev)
      Dprev = 0.5;
end

D = Dprev;
PA=VA*IA;
DeltaVA=VA-VAprev;
DeltaPA=PA-PAprev;

if DeltaPA>0
      if DeltaVA>0
      D=Dprev-0.001;
      VA=VAprev+DeltaVA;
      elseif DeltaVA<0
      D=Dprev+0.001;
      VA=VAprev-DeltaVA;
      end
elseif DeltaPA<0
      if DeltaVA>0
      D=Dprev+0.001;
      VA=VAprev-DeltaVA;
      elseif DeltaVA<0
      D=Dprev-0.001;
        VA=VAprev+DeltaVA;
      end
end

if D>0.9
      D=0.9;
elseif D<0
      D=0;
end

VAprev=VA;
PAprev=PA;
Dprev=D;
```

FYDP (C) Spring 2023 Summary of Team Log Book/ Journal

Project Title: Design And Implementation Of An Appropriate Motor Controller To Improve The Range Of An E-Bike.

Group: 03

Final Year Design Project (C) Spring 23			
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FYDP (C) Spring 2023 Summary of Team Log Book/ Journal

Date/Time/Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
26.01.2023 **(FYDP Committee, meeting 01)**	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi **Speaker:** **Abu S.M Mohsin, PhD**	Introduction of FYDP-(EEE400C)- a. Explained how to write the report briefly. b. Clarified the course outcome and Complex Engineering Problem attributes.		
02.02.2023 **(Group Meeting 1 about paperwork)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1**: Editing logbook **Task 2:** Report writing a. Introduction b. Chapter 4 (optimal solution c. Chapter 9 (Ethics And Professional Responsibilities) **Task 3:** Paperwork for prototype.	Task 1: Fariha Task 2: Everyone a. Fariha b. Sadab,Rafid Ridwan c. Md. Rafid Task 3: Everyone worked on at least one paper. **Progress:** Task 1: Partially Completed Task2: Partially Completed Task3: Partially Completed	

FYDP (C) Spring 2023 Summary of Team Log Book/ Journal

04.02.2023 **(ATC panel meeting 01)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task 1:** Overall brief about EEE400C guidelines. **Task 2:** Edit logbook and report writing. **Task 3:** Told us to start buying parts of the prototype.	Task 1: Everyone Task 2: Everyone Task 3: Everyone **Progress:** Task 1: Partially Completed Task 2: Partially Completed Task 3: Partially Completed	1. Tasks should be more specific for each member.
08.02.2022 **(Group meeting 02)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Editing logbook **Task 2**: Report writing a. Chapter 7 (project progress), 11 (Complex Engineering Problems And Activities) b. Chapter 3 (IT tools), 9 (Ethics And Professional Responsibilities) c. Chapter 4 (optimal solution), 10 (conclusion) **Task 3:** Working on buying parts of the prototype.	Task 1: Fariha Task 2: a. Fariha b. Md. Rafid c. Sadab, Rafid Ridwan Task 3: Everyone **Progress:** Task 1: Partially Completed Task 2: Partially Completed Task 3: Partially Completed	

FYDP (C) Spring 2023 Summary of Team Log Book/ Journal

11.02.2023 **(ATC panel Meeting 02)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task 1:** Logbook and report review by the ATC panel and provided the guideline about corrections of the report. **Task 2:** Asked us about components buying.	Task 1: Everyone Task2: Everyone **Progress:** Task 1: Completed Task 2: Partially completed.	**Correction of report-** 1. Asked us to send an email of the paper that we could not access. 2. Asked us to have at least two group meetings. 3. Correct formatting errors and complete cover page. 4. Citation numbers before the full stop.
14.02.2022 **(Group Meeting 03)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1**: Editing logbook **Task 2**: Report writing a. Chapter 9 (Ethics And Professional Responsibilities) (Intro) b. Chapter 3(IT tools) c. Chapter 2 (Project design), 4 (optimization) **Task 3**: Font, table, figure alignment corrections.	Task 1: Fariha Task 2: a. Fariha b. Md. Rafid c. Sadab, Rafid Ridwan Task 3: Everyone **Progress:** Task 1: Partially Completed Task 2: Partially Completed Task 3: Completed	
16.02.2023 **(Group Meeting 04)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1**: Received the battery and the solar charge controller. **Task 2:** Went to look for the chassis of the bike.	Task 1: Fariha, Rafid Ridwan Task 2: Md. Rafid, Sadab **Progress:** Task 1: Completed Task 2: Partially completed	

FYDP (C) Spring 2023 Summary of Team Log Book/ Journal

18.02.2023 **(ATC panel Meeting 03)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman 3. Mohammad Tushar Imran **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task 1:** Asked to be precise at all the corrections on the report and logbook. **Task 2:** Asked us to change the solar panel rating. **Task 3:** Risky events have to be more detailed.	Task 1: Fariha Task 2: Rafid Ridwan Task 3: Sadab, Md Rafid **Progress:** Task 1: Completed Task 2: Completed Task 3: Completed	**Correction of logbook-** 1. Alignment. 2. meeting number and speaker name. 3. ATC class explanation, briefly. 4. Do not include informal meetings. **Correction of report-** 1. Submission date may change. 2. All figures have to be in one color. 3. All the references on the left-justified. 4. Citation in IEEE format. 5. European Standards and Codes in detail.
23.02.2023 **(Group Meeting 05)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Report Writing a. Chapter 6 (Impact analysis), Chapter 10 (Conclusion) b. Chapter 7 (Plan of the project), Chapter 9 (Ethical consideration) c. Chapter 4 (Optimization) d. Chapter 11 (Complex engineering problem) **Task 2:** Editing logbook	Task 1: a. Shahed Sadab, Rafid Ridwan b. Md. Rafid, Fariha c. Shahed Sadab, Rafid Ridwan d. Md. Rafid, Fariha Task 2: Fariha **Progress:** Task 1: a. Completed b. Completed c. Partially Completed d. Completed Task 2: Completed	

24.02.2023 **(Group Meeting 06)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Simulation Graph Correction a. Approach 1 & 2 b. Approach 3 & Backup Battery Task 2: Organizing all the parts of the prototype and discussion on how to assemble everything.	Task 1: a. Shahed Sadab b. Rafid Ridwan Task 2: Everyone **Progress:** Task 1: a. Completed b. Completed Task 2: Partially completed	
28.02.2023 **(ATC panel Meeting 04)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman 3. Mohammad Tushar Imran **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task 1:** Review of the logbook and provided suggestions about including some description of the report chapters in. **Task 2:** Review of the report and recommended to update the rest of the simulation result graphs. **Task 3:** Displayed the components of the project to the ATC panel.	Task 1: Fariha, Md. Rafid Task 2: Rafid Ridwan, Sadab Task 3: Rafid Ridwan **Progress:** Task 1: Completed Task 2: Completed Task 3: Completed	**Correction of logbook-** **1.** Briefly describe the chapter names in the logbook. **2.** Fill out all the columns properly. **Correction of report-** **1.** Update the remaining resultant graphs and its background. **2.** Start writing the incomplete chapters (chapter 8).
01.03.2023 **(Group Meeting 07)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** First attempt of the hardware testing of the backup battery charging system using available solar panels.	Task 1: Everyone **Progress:** Task 1: Completed	

02.03.2023 **(FYDP Committee, meeting 02)**	**Speaker:** 1. Abu S.M. Mohsin, PhD. **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Progress Presentation of FYDP 400C**	Task 1: Introduction was done by Fariha Task 2: Prototype video demonstration was done by Sadab Task 3: Optimal design explanation was done by Rafid Ridwan Task 4: Conclusion and other CO sections done by Rafid **Progress:** Task 1: Completed Task 2: Completed Task 3: Completed Task 4: Completed	**1.** Finished our presentation on time accordingly. **2.** Asked us if we had made any innovations in solving technical challenges and our contributions. **3.** Asked us to add more relevant data on project

03.03.2023 **(Group Meeting 08)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Simulation Graph Correction a. Approach 1 & 2 b. Backup battery **Task 2:** Report editing a. Chapter 1 (literature gap) b. Chapter 8 (Economical analysis) c. Chapter 8 (Financial aspects) d. Chapter 9 (Ethical issues) e. Chapter 8 (Introduction & Conclusion) f. Chapter 8 (Cost-Benefit) **Task 3:** Logbook editing	Task 1: a. Shahed Sadab b. Rafid Ridwan Task 2: a. Fariha b. Sadab, Rafid Ridwan c. Sadab d. Md. Rafid e. Fariha, Md. Rafid f. Sadab, Rafid Ridwan Task 3: Fariha **Progress:** Task 1: a. Completed b. Completed Task 2: a. Partially Completed b. Completed c. Completed d. Completed e. Completed f. Completed Task 3: Completed	

04.03.2023 **(ATC panel Meeting 05)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman 3. Mohammad Tushar Imran **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task 1:** Reviewed the logbook and provided suggestions about correcting some errors. **Task 2:** Suggested adding some pictures of the components and asked us to show the prototype progress.	Task 1: Fariha, Md. Rafid Task 2: Rafid Ridwan, Sadab **Progress:** Task 1: Completed Task 2: Completed	**Correction of logbook-** **1.** Asked us to write the update of workshop permission in the logbook. **Correction of report-** **1.** Suggested us to add the pictures of the component **2.** Pictures of prototype development **3.** Asked us to review the report once again to fix a few typographical errors.
09.03.2023 **(Group Meeting 09)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Logbook update **Task 2:** Report update, final design and validation a. Introduction b. Update of final report, chapter 5.2 (components and descriptions) c. Update Final year design report section 5.3.	Task 1: Fariha Task 2: a. Md. Rafid b. Fariha, Rafid Ridwan c. Sadab **Progress:** Task 1: Partially completed Task 2: Partially completed	

14.03.2023 **(Group Meeting 10)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Identifying and labeling the various operations of the motor controller. **Task 2:** Started constructing a trainer board using a plastic board with all the components, switches, and testing wires/probs required for gathering data.	Task 1: Fariha and Md. Rafid Task 2: Rafid Ridwan and Sadab **Progress:** Task 1: Partially completed Task 2: Partially completed	
16.03.2023 **(Group Meeting 11)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi **Absent student:** 1. Md. rafid **Reason:** He was absent due to high fever and digestion problems.	**Task 1:** Building a trainer board where, a) Controller, b) Throttle, c) Brakes, d) Display and e) Battery are set in such a way that all the components are visible and can easily be tested. **Task 2:** Connecting the power source and measure of the a) SOC of the initial battery b) measure the initial speed(Km/h) of the freely moving wheel and c) Checking if the electric brake procedure works or not.	Task 1: Rafid Ridwan, Fariha and Sadab Task 2: Rafid Ridwan, Fariha and Sadab **Progress:** Task 1: Partially completed Task 2: Partially completed	

FYDP (C) Spring 2023 Summary of Team Log Book/ Journal

18.03.2023 **(ATC panel Meeting 06)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman 3. Mohammad Tushar Imran **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task1:** Reviewed the report and gave us some recommendations for revising some of the chapters' introductions and conclusions. **Task 2:** Reviewed the logbook and suggested to correct some errors. **Task 3:** Asked us to demonstrate the videos and the photos of prototype testing.	Task 1: Everyone Task 2: Everyone Task 3: Everyone **Progress:** Task 1: Completed Task 2: Completed Task 3: Completed	**Correction on logbook:** **1.** ATC meeting 5 needs to be edited. **2.** Asked us to rephrase some of the comments. **Correction on report:** **1.** Advised us to start adding the page numbers in the tables and figures. **2.** All the figures and table numbers should be at font size 10. **3.** Told us to add references in the problem statement, literature gap and the future industry. **4.** Appendix should be in the previous page. **5.** Advised us to start writing the hardware tool. **6.** Conclusion of IT tools, Ethical Responsibilities and Introduction of Engineering Project Management should be rechecked. **7.** Attributes part should be rechecked as well. **8.** Reference format should be re-checked with the IEEE format.

21.03.2023 **(Group Meeting 12)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Report Editing a. Chapter 3 (Hardware part) b. Chapter 3.4 (IT tools conclusion) c. Chapter 6.4 (Impact analysis conclusion) d. Chapter 7.1 (Project management introduction) **Task 2:** Logbook editing	Task 1: a. Md. Rafid b. Sadab c. Rafid Ridwan d. Fariha Task 2: Fariha **Progress:** Task 1: Completed Task 2: Completed	
22.03.2023 **(Group Meeting 13)** (Offline meeting)	**Students:** 1. Fariha Oishi 2. Shahed Sadab 3. Rafid Ridwan 4. Md. Rafid	**Task 1:** a. Putting the components together for testing the peak speed, and recording it. b. Collecting data for a minute at a time. **Task 2:** Testing the electric braking system. a. Braking while being at constant speed enables regenerative braking. b. Slowing down the motor from constant speed to 0 in around 12.87 seconds with braking.	Task 1: Rafid Ridwan, Fariha Task 2: Sadab, Md. Rafid **Progress:** Task 1: Partially completed Task 2: Partially completed	

23.03.2023 **(Group Meeting 14)** (Offline meeting)	**Students:** 1. Fariha Oishi 2. Shahed Sadab 3. Rafid Ridwan 4. Md. Rafid	**Task 1:** Testing and taking data of supply voltage, current, power and energy values within a 5 minutes time frame without using any electric brake by keeping the motor at a constant speed of 35 km/h. **Task 2:** Collected data of current, voltage, power, speed and energy using regenerative braking system for 5 minutes. Noted the battery drainage with and without using regenerative braking. **Task 3:** Workshop approval	Task 1: Rafid Ridwan, Fariha Task 2: Sadab, Md. Rafid Task 3: Everyone **Progress:** Task 1: Partially completed Task 2: Partially completed Task 3: Completed	
24.03.2023 **(Group Meeting 15)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Report Editing **a.** Completion Of Final Design Chapter b. Reference Editing c. Selection of IT tool **Task 2:** Logbook editing	Task 1: a.Md. Rafid, Sadab b. Fariha c. Rafid Ridwan Task 2: Fariha **Progress:** Task 1: Partially Completed Task 2: Completed	

25.03.2023 **(ATC panel Meeting 07)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman 3. Mohammad Tushar Imran **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task1:** Reviewed the report and gave us some suggestions of improvement. **Task 2:** Reviewed the logbook and suggested to correct errors about proper description of report chapters. **Task 3:** Asked us to show the improvement of the prototype and suggested to start working on a field test.	Task 1: Everyone Task 2: Everyone Task 3: Everyone **Progress:** Task 1: Completed Task 2: Completed Task 3: Completed	**Correction on logbook:** **1.** Description for the progress presentation date. **2.** Instructed us to write down the name of the chapters. **3.** Numerical value errors. **Correction on report:** **1.** Told us to work on the reference sequence. **2.** Asked us to add comparative study analysis.
26.03.2023 **(Group Meeting 16)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Report Editing a. Completion of the final design chapter. b. Reference editing. **Task 2:** Logbook editing.	Task 1: Everyone Task 2: Fariha, Md. Rafid **Progress:** Task 1: Partially Completed Task 2: Completed	

28.03.2023 **(Group Meeting 17)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Working on prototype. a. Calculating the power and energy consumption at different times. b. Noting down the collected data and making comparisons between usage of regenerative braking and using traditional friction braking. **Task 2:** Logbook updation.	Task 1: a. Rafid Ridwan, Sadab. b. Fariha, Md. Rafid. Task 2: Fariha **Progress:** Task 1: Completed Task 2: Completed	
30.03.2023 **(Group Meeting 18)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Working on prototype. a. Assembling and wiring all the components in the cycle chassis and testing how the system performs. b. Taking necessary pictures and videos of the working bike. Also taking some data out of it. **Task 2:** Logbook updation.	Task 1: Everyone Task 2: Fariha **Progress:** Task 1: Partially Completed Task 2: Completed	

01.04.2023 **(ATC panel Meeting 08)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman 3. Mohammad Tushar Imran **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task1:** reviewed the report and provided us with some amendments. **Task 2:** reviewed the logbook while providing modification remarks for a few sections. **Task 3:** Asked to show last week's field test values with different loads on the e-bike.	Task 1: Everyone Task 2: Everyone Task 3: Everyone **Progress:** Task 1: Completed Task 2: Completed Task 3: Completed	**Correction on logbook:** **1.** Recommended changing the structure of Task 3 as of March 25. **2.** It was suggested that we be more detailed in our states on the corrective segment of the logbook. **3.** Asked us to inform the ATC members about the real time test voltage & current values through video or directly. **Correction on report:** **1.** Suggested to add the block diagram of the approaches first then to add descriptions. **2.** Recommended us to modify the flow chart as well. **3.** Asked to add a duration period on the gantt chart. **4.** Suggested us to start writing on evaluate project progress

3.04.2023 **(Group Meeting 19)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Working on prototype. **a.** Mounted multimeter for current and voltage measurements and also mounted a mobile phone to record the speedometer & multimeter values while riding. **b.** Recorded some videos of the speed, current consumption, traveled distance for the specific time from the display and multimeter with load. **Task 2:** Logbook updation.	Task 1: a. Rafid Ridwan, Fariha. b. Sadab, Md. Rafid. Task 2: Fariha, Rafid Ridwan. **Progress:** Task 1: Partially Completed Task 2: Completed	
5.04.2023 **(Group Meeting 20)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Working on prototype. **a.** Continuing the task of measuring current & voltage supply, energy consumption for two different loads and also observing the battery's SOC after a certain time frame. **b.** Taking all the data to create some table of data and chart to observe the changes in current consumption and supply. Also observing the energy consumption differences between different loads.	Task 1: a. Everyone b. Everyone **Progress:** Task 1: Completed	

6.04.2023 **(Group Meeting 21)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Report Editing, a. Completion of the final design chapter. b. Evaluate project progress chapter. c. Graphs and flowchart editing. d. Completion of final design conclusion. **Task 2:** Logbook editing.	Task 1: a. Sadab, Md. Rafid, Rafid Ridwan. b. Rafid ridwan, Fariha, Sadab. c. Md. Rafid. d. Fariha. Task 2: Fariha, Rafid Ridwan **Progress:** Task 1: Partially Completed Task 2: Completed	

08.04.2023 **(ATC panel Meeting 09)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman 3. Mohammad Tushar Imran **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task1:** Reviewed the report and provided us with a few suggestions. **Task 2:** Reviewed the logbook. **Task 3:** Asked us to take the data on supplied and consumed energy simultaneously.	Task 1: Everyone Task 2: Everyone Task 3: Everyone **Progress:** Task 1: Completed Task 2: Completed Task 3: Completed	**Correction on logbook:** **1.** Suggested summarizing the meeting minutes as a task. **Correction on report:** **1.** suggested that we include a plagiarism check result. **2.** Recommended to add the budget of FYDP-P and FYDP-D **3.** Asked to improve the graph of comparison between energy consumed by the motor with and without using regenerative braking. **4.** Advised that we provide the poster draft before the next meeting.

09.04.2023 **(Group Meeting 22)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Working on prototype. a. Simultaneous voltage and current measurement using two multimeters with friction brakes. b. Simultaneous voltage and current measurement using two multimeters with regenerative brakes and calculating energy consumptions. **Task 2:** Logbook updation.	Task 1: a. Sadab, Fariha b. Rafid Ridwan, Md. Rafid Task 2: Fariha **Progress:** Task 1: Completed Task 2: Partially Completed	
10.04.2023 **(Group Meeting 23)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Report Updation a. Final Design chapter completion b. Creating real time voltage & current graph with respect to time and analyzing acquired data for different loads. **Task 2:** Poster editing a. Environment and sustainability. b. economic analysis c. Future work, Conclusion d. Reference, Acknowledgement	Task 1: a. Everyone b. Md. Rafid Task 2: a. Sadab b. Rafid Ridwan c. Md. Rafid d. Fariha **Progress:** Task 1: Partially Completed Task2: Partially Completed	

12.04.2023 **(Group Meeting 24)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Working on prototype. a. Field test to observe the overall mileage from fully charged condition. b. Charging Battery using MPPT charge controller to extend the battery life. **Task 2:** Logbook updation.	Task 1: a. Everyone b. Everyone Task 2: Fariha **Progress:** Task 1: Completed Task 2: Partially Completed	
13.04.2023 **(Group Meeting 25)** (Online meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Continuation of Poster editing a. Methodology b. Result c. Abstract d. Introduction, Objective e. Design approach **Task 2:** Updation of Chapter-05 a. Correction of data chart of 5.3.4 b. Correction of data chart of 5.3.5 c. Correction of data chart of 5.3.6 d. Correction of data chart of 5.3.7 e. Correction of data chart of 5.3.8 f. Correction of data chart of 5.3.9 g. Correction of data chart of 5.3.10 h. Correction of data chart of 5.4 **Task 3:** Logbook updation.	Task 1: Everyone Task 2: a. Rafid Ridwan b. Shahed Sadab c. Md. Rafid d. Fariha Oishi e. Md. Rafid f. Rafid Ridwan g. Shahed Sadab h. Fariha Oishi Task 3: Fariha **Progress:** Task 1: Completed Task 2: Completed Task 3: Completed	

15.04.2023 **(ATC panel Meeting 10)**	**ATC Members:** 1. Dr. AKM Abdul Malek Azad(Chair) 2. Dr. Touhidur Rahman 3. Mohammad Tushar Imran **Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Fariha Oishi 4. Md. Rafid	**Task 1:** Reviewed the poster and provided us with a few suggestions.	Task 1: Everyone **Progress:** Task 1: Completed	**Correction on poster:** **1.** Asked us to add the ATC panel number.. **2.** Suggested that we clarify different parts of the poster. **3.** Recommended us to make alterations to the objective. **4.** Suggested us to revise some typographical errors. **5.** Advise us to have a plan for the final showcase. **Correction on report:** **1.** Asked to add the ethics statement of the similarity check report.
17.04.2023 **(Group Meeting 26)** (Offline meeting)	**Students:** 1. Rafid Ridwan 2. Shahed Sadab 3. Md. Rafid 4. Fariha Oishi	**Task 1:** Working on poster corrections. **Task 2:** Completing the report and also acquiring the report of plagiarism check from the librarian. **Task 3:** Completing the logbook.	Task 1: Everyone Task 2: Everyone Task 3: Fariha **Progress:** Task 1: Completed Task 2: Completed Task 3: Completed	